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Fall Meeting of the American Welding Society

The Fall Meeting of the AMERICAN WELDING SOCIETY will be held in Buffalo during the week of October 3rd in connection with the Metal Congress.

Other societies meeting at the same time are American Society for Steel Treating; Iron and Steel and Institute of Metals Divisions of the American Institute of Mining and Metallurgical Engineers; Iron and Steel Division of the American Society of Mechanical Engineers; Production Activity Division of the Society of Automotive Engineers; and the Wire Association.

The Meetings and Papers Committee has made strenuous efforts to make the technical program one of the best in the history of the AMERICAN WELDING SOCIETY and has succeeded to a remarkable degree. There will be important papers giving the results of the latest researches in fundamentals of welding as conducted by the leading universities of the United States. There will be a special session on non-ferrous metal welding and also on merchandising of welded products. There will be papers on welding of machinery parts and large structures. Applications to pressure vessels, the iron and steel industry and dairy industry are featured as are, also, the training of operators. The welding of special ferrous metals and alloys is given consideration. In all, there are more than twenty-five papers scheduled.

Welding has advanced remarkably during the past few years and this meeting offers a unique opportunity to keep abreast of the latest developments. Special features are being provided for the ladies' entertainment. Kindly note dates and plan to attend.

Dr. Adolf Krebs Was a Noted Scientist and Engineer

Dr. Adolf Krebs, well-known consulting engineer and manufacturer, died suddenly at his home, 37 Robinwood Avenue, Jamaica Plain, on Wednesday, June 15th. He was born on Dec. 19, 1864, at Wiesbaden, Germany, the son of Dr. Georg Krebs, an eminent German professor who was a physicist and scientific author of the time.

His education was completed at the University of Berlin, where he obtained the degree of Ph.D., and at the Charlottenburg Polytechnic Institute, where he studied electrical engineering. He was then connected with the German General Electric Company and Siemens & Halske, in important engineering and administrative positions, being secretary to Wilhelm von Siemens and for years Siemens' chief engineering and financial representative in Rio de Janeiro and other parts of South America, in connection with new electric developments in those countries.

He first came to the United States in 1893, as the Siemens representative at the World's Fair in Chicago. He finally settled in this country in 1908 and had been in business here ever since, especially in the oxyacetylene welding industry, in Boston. He was a pioneer in this industry and was prominently known, both in the United States and in Europe, as an inventor, engineer and authority in the oxyacetylene industry. As an inventor and manufacturer, he was responsible for many outstanding developments, notably in oxyacetylene cutting machines, and he was active in this work until his death, being treasurer of the General Welding & Equipment Company of Boston.

Dr. Krebs was the author of "Modern Steam Turbines and Turbine Ships," published in German and French in Brussels in 1904 (3rd edition in 1908), and of "Cutting with Oxygen," published in Boston in 1926.

On Feb. 16, 1895, Dr. Krebs married, in Berlin, Germany, Marguerite Fleran, a native of Antwerp, Belgium, who survives him. He leaves also a son, Carlos Krebs, who was associated with him in his business, as well as a daughter, Miss M. Marguerite Krebs, and the family includes a grandchild, Charlotte Krebs. Dr. Krebs was a member of the University Club, as well as of various technical associations in this country and in Europe.

Dr. Krebs, until his death, was a member of the Executive Committee of the Boston Section of the AMERICAN WELDING SOCIETY.

SAN FRANCISCO

The following are the officers elected by members of the San Francisco Section for the coming season:

Chairman—K. V. King.

Vice-Chairman—C. S. Smith, Linde Air Products Co.

Secretary-Treasurer—H. W. Saunders, Air Reduction Sales Co.

Executive Committee Member—C. A. Britton, Central High School.

IMPORTANT NOTICE

In publication of the article by F. R. Freeman, on "The Strength of Arc Welded Joints" in the June issue giving the results of a series of tests made in England on arc welded specimens, attention is called to the fact that the British ton is equal to 2240 pounds.

NAVY AND ARMY OFFICERS WIN MAJOR AWARDS IN SECOND LINCOLN ARC WELDING PRIZE COMPETITION

(From a News Release)

Winners of arc welding prize competition which shows estimated savings of almost $1,000,000,000 are paid with new and unusual form of checks.

In peace as well as war the navy cooperates and competes with the army. This was demonstrated when Lt. Com. Homer N. Wallin, U. S. N., and Lt. Henry A. Schade, U. S. N., working in collaboration on the paper submitted, won first prize in the Second Lincoln Arc Welding Prize Competition sponsored by The Lincoln Electric Company of Cleveland, Ohio. Second prize was won by Major G. M. Barnes, U. S. A.

A résumé of the savings to be effected by using arc welding extensively in all industries as shown by the approximately 400 papers submitted in the competition shows an estimated saving to industry of almost a billion dollars a year, provided the process was used as extensively as possible.

The jury, under the direction of Prof. E. E. Dreese of Ohio State University, awarded first prize of $7500 to the two naval officers who submitted the prize-winning paper. Both officers were members of the Construction Corps at the Navy Yard, Mare Island, California, but Lt. Schade has since been transferred to Washington. The title of their paper is "The Design and Construction of an Arc Welded Naval Auxiliary Vessel."

Major G. M. Barnes, U. S. A., Chief of Design and Engineering, Ordnance Department, Watertown (Mass.) Arsenal, won second prize of $3500 for his paper, "Manufacture of Ordnance at Watertown Arsenal Revolutionized through Arc Welding."

"The Application of Arc Welding to the Design of Steel Buildings for the Resistance of Earthquake Forces" won third prize of $1500 for H. H. Tracy, Structural Engineer of the Southern California Edison Company, Ltd., of Los Angeles.

A $750 fourth award went to Gustav F. D. Wahl and Harry E. Johns, Kiel, Germany, for a paper on a special river-sea bulk cargo ship. H. J. L. Bruff of Harrowgate, England, won fifth prize of $500 for "Strengthening Weak Iron and Steel Bridges by Arc Welding." A paper on arc welding steel cars won $250 for William H. Zorn of Wyandotte, Michigan. Thirty-five additional prizes of $100 were awarded to writers of papers which showed the application of and savings possible by arc welding in every industry.

The first prize-winning paper describes the construction of an arc welded auxiliary vessel for use with the fleet at San Pedro. The hull is conventional ship-shape in form and is 118 ft. long, with a full load displacement of 300 tons. Speed of the craft is 10 knots.

Arc welding has been in use by the navy since 1917 when sabotaged engines of seized German liners were repaired by this process. Since displacements of naval vessels have been limited by international treaties the navy has begun to look upon arc welding as a standard method of construction. The process is supplanting riveting over a wide range of applications in increasing amounts on each new ship, as it becomes more and more evident that lighter structures of equivalent strength, rigidity and shock resistance may be obtained by welding.

In addition to the partial use of arc welding on large ships the navy has substituted welding completely for riveting on a considerable number of smaller ships. The welded vessel was built at a 10% saving over riveted construction. In addition a riveted ship of the same size, being 17% heavier, has a correspondingly reduced carrying capacity. The welded ship therefore yields greater service for a smaller investment. The total savings, direct and indirect, during the lifetime of the arc welded vessel, will be enormous and out of all proportion to the savings in first cost.

Arc welding had never been used in the construction of gun carriages until the 3" Anti-aircraft mount (mobile) described in Major Barnes' paper was built. This piece of ordnance was selected because, in addition to being the most modern type of post-war carriage standardized by the army, it was subjected to severe road tests in addition to the impact forces due to firing. The principal parts of the carriage are highly stressed and of intricate design.

The substitution of welded steel members for castings in the piece of ordnance described by Major Barnes has shown such decided advantages in strength, weight saved and lower costs that it has brought about the adoption of welding as an approved method of manufacture for ordnance structures.

The tremendous savings and improved design of the ordnance structures mentioned here are typical of the results which can and are being secured in every industry utilizing iron and steel by the use of arc welding. Other papers submitted in the competition point out these savings.

Mr. Tracy's paper on arc welded steel buildings to resist earthquake shocks deals with the construction of a thirteen story general office building of the Southern California Edison Company, Ltd., at Los Angeles. By the application of arc welded construction the structure will resist seismic shocks of an intensity comparable to those which would be produced by a disturbance similar to the San Francisco earthquake of 1906 or the Tokyo earthquake of 1923.

Ideas, research findings and welding techniques advanced in the papers submitted indicate that arc welding is playing an increasingly important part in industry every year. Prize papers will be published in book form.

The first three prize winners received what are believed to be the most unusual checks ever issued. These three checks represented first, second and third prizes in the prize competition and were written by welding a head on a steel plate.

Local Member Honored

The Engineering Society of Buffalo has elected Mr. G. W. Swan, District Manager of J. A. Roebling's Sons Company, President of the Society for the year 1932–1933. Mr. Swan is well known to the members of the Society and has served as Secretary-Treasurer and Chairman of the Western New York Section.

Welding Association in Poland

The Association for the Development of Welding and Cutting of Metals in Poland, Warsaw, 6 Hortensja Str., has published its annual report covering the first four years of existence of the association, 1927–1931. At the end of the report the subject-matter is briefed in both French and German.

The purpose of the Association is as evidenced by its name. The report deals principally with the details of welding and cutting schools organized and carried on. It states that they have held 83 courses of instruction in welding with a total of 2287 pupils, among whom were 245 engineers and technicians, and 40 instructors of professional schools. The report further states that the official organ of the Association is the monthly journal, "Spawanie i Ciecie Metali." This publication treats important welding developments not only in Poland but in foreign countries. The report states that during the year 1931 alone 24 conferences were held in the larger industrial cities of Poland, the conferences being devoted to the problems in the welding and cutting industry.

The Association collaborates with the Ministry of Industry and of Commerce in the establishment of regulations involving the use of acetylene and other gases and in welding and cutting. The Association keeps in touch with similar organizations in foreign countries, principally with the Commission Permanente Internationale de l'Acetylene et de la Soudure Autogene a Paris, of which it is an active member.

Welding Loads Jump to Five Figures

(Reprinted from April 2, 1932, issue of Electrical World.)

Far-sighted as it has been, the power industry has seldom faced loads that it was not prepared to supply. Missionary work in new fields has usually been anticipated by provision of system capacity to meet whatever business was won. This has been true in general even of electric welding, but so fast is the acceptance of that process taking place that the reverse may at any time be true. Flash welding of pipe seams at the rate of 35 to 40 feet per minute requires an input of about 1200 kilowatts. In a still more profligate use of power to attain process speed whole 36-foot lengths of two-foot pipe, one-half inch thick, are being welded at one time by a battery of ten or twelve welding machines operating in parallel. The job is done in one minute, and the power required totals 11,000 kv-a.

Compiling the 1931 developments, the Meetings and Papers Committee of the AMERICAN WELDING SOCIETY includes these instances and concludes that "the only limit to the size and power of electric welders is the amount of power that the power companies will be able to furnish to customers for welding purposes."

This constitutes a challenge. The power companies have never sidestepped such an issue. Those who can see this one coming their way will do well to forsake the alibi defense, plead guilty if they are caught unprepared and undertake to conform. It will be a big system that can meet such loads concentrated at one point. There are two "ifs." One pertains to the jolt experienced by the generating units and transformation units on the system, and the other to the jolt pretty sure to be given to service of neighboring customers. The "ifs" will fade as fast as measures for meeting abrupt changes in load and voltage are extended downward from the realm of the interconnected system into the province of the localized situation. It is another case where the once cute little tot has suddenly been recognized as a strapping youngster.

Welding Here and Abroad

(Reprinted from March 24, 1932, issue of Engineering News-Record.)

Coincident with the remarkable growth in the utilization of structural welding in this country, European engineers have steadily been adding to the number and type of their welded structures. While a detailed quantitative comparison of accomplishment is not available, it is apparent that American engineers have made the most rapid strides in applying welding to tall buildings. On the other hand, European engineers can point to more all-welded bridges of substantial size. Of the four longest welded truss bridges in existence three are in Europe. The single American bridge, that at Chicopee Falls, Mass., is a railway structure and is thus heavier than the European bridges, which are for highway service. Until recently the Chicopee Falls bridge could also boast the longest span, but the new Czechoslovakian bridge described in this issue exceeds it materially. Although most of the all-welded bridges are in Europe, it is worth recording that American railroad engineers have been particularly active in utilizing welding for the repair or reinforcement of bridges, a recent compilation giving 75 existing bridges in which welding has been utilized to a major degree in repair and alteration work; highway engineers have been

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Discussion of Annual Meeting Papers, American Welding Society, New York, April 27 to 29, 1932

WEDNESDAY MORNING SESSION

E. H. Ewertz, Past-President, Presiding

BEING an old shipbuilder myself and having spent most of my life in that activity, I naturally take pride in whatever can be done in that field, and particularly when what is done is actual progress in the line of better ships at a lower first cost and a lower maintenance cost

We have three papers before us today and it will be unfair on my part to stand here and tell you what I think about either the substance of the papers or the subject as a whole, but the papers do one thing that I want to emphasize particularly: They stress and explain the vast necessity for careful study of design and procedure which is the foundation for successful welded ship construction.

It has been generally conceded that the Navy Department of this country has been ultra-conservative in its activities and hasn't led the way as much as the industrial party has felt should be the case. I think that these ideas are based on a misunderstanding of the facts. In my experience with the Navy Department (and I have had quite a little of it) it is evident that a foundation must be laid, a solid foundation must be laid, before the work can branch out in various divisions, and I don't care to say how far back it is since the Navy Department started to investigate welding, but I think it dates back to almost the days when some of us were first playing with that new art. The fact that that foundation was carefully laid will be more clearly demonstrated to you by the first paper of this morning which refers to or covers the welding on the U. S. S. *New Orleans*.

Captain J. O. Gawne of the U. S. Navy presented his paper on "Welding in the Construction of the U. S. S. *New Orleans*."*

CHAIRMAN EWERTZ: I think the paper that has just been read and the illustrations which have been shown check up with what I tried to draw your attention to, that the Navy Department is making very rapid progress based on a very excellent knowledge of the work.

The picture of the submarine rescue chamber was of particular interest to me, because, having had the pleasure of building the *Holland* and since that time some hundred odd submarines and having the pleasure of being down at all kinds of depths on tests in submarines, you would think that I would be very pleased to know that there is a definite way to get away from a submarine in an emergency. I have been out in some pretty nasty accidents which didn't prove fatal, however, to anybody, but, knowing how a submarine is constructed and the care taken to construct that vessel and knowing the training that the Navy Department compels the men to go through who operate those submarines, it is a very rare thing for a major accident to happen to a submarine except during war—and I have never been afraid to go down and I am still here to tell the story.

The next paper deals more definitely with the foundation work for welding on Navy ships.

Mr. L. C. Bibber, who is in charge of welding design at the Bureau of Construction and Repair in Washington, presented his paper on "Experimental Determination of Stresses in Welds."*

CHAIRMAN EWERTZ: I had the pleasure two weeks ago of talking to a man who has charge of welding in one of our shipyards where they were doing some converting and alteration work on some passenger ships and he told me that they estimated the welding on each ship would be somewhere around 60,000 feet. If you put 60,000 feet of welding into a steel structure of Prof. McKibben's design, it would be quite a structure. I don't say that to minimize the steel structure at all but more to emphasize the necessity of careful study and careful design as emphasized in these two first papers that we have heard today.

The next paper on welded barges built by the Federal Shipbuilding and Dry Dock Company is the commercial aspect of welding as applied to ship construction.

Mr. Gordon G. Holbrook, General Superintendent of the Federal Shipbuilding and Dry Dock Company, presented his paper on "Welded Barge Construction."†

CHAIRMAN EWERTZ: We have with us here today a number of gentlemen who are active in the work that has been presented and have made a close study of the various phases of it, and I am sure that we will be able to spend a short time left of our morning meeting to great advantage if we can have some discussion. I may ask that the discussion, due to the necessity of time, be brief.

MR. H. W. PIERCE (New York Shipbuilding Co.): Mr. Chairman and Gentlemen: I have certainly enjoyed the paper that was presented by Cap. Gawne and I want to congratulate him and his associates on the very comprehensive review of the welding on that cruiser. Those who have not had the opportunity to witness the work on these cruisers will doubtless regard this paper with interest and, I may add, probably some surprise. To those of us who have seen these ships take form this paper is of even greater value in its presentation of the solution, at least as practiced at the New York Navy Yard, in welding problems applied to shipbuilding.

Fitting welding into the industrial plant has become one of the industry's leading problems, and nowhere is that problem more complicated by the multiplicity of associated trades, by the nature of the erection and material handling, as well as by tradition and custom, as it is in shipbuilding. That is not to say that the technical problems in connection with welding have been solved. We have come to know something of the art and bit by bit the idea is being sold to the people who ultimately pay the bill—in other words, the owners. But in many ways (and I include all industrial plants, not merely shipbuilding plants) there is much to be done in the matter of organization in order that welding may be on an economical basis.

The extent to which welding is used must be a surprise

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* Published in May issue of JOURNAL OF THE AMERICAN WELDING SOCIETY.
† Published in April issue of JOURNAL OF THE AMERICAN WELDING SOCIETY.

to many, for prior to Captain Gawne's paper there has been very little published, to my knowledge, on the extent of welding in shipbuilding and more particularly in the Navy where it is used to so great a degree. After all, it remains for a representative of the Navy to publish matters in connection with our war vessels.

It has been the good fortune of the company which I represent to have built or have building four of these cruisers. The first, the *Salt Lake City*, was a sister ship to the *Pensacola*, to which Captain Gawne made some reference. The next, the *Chester*, had only slightly more welding. The design had been changed radically and not so much thought had been given to the extension of welding. The third, which is rapidly approaching completion, has much more, and I thought some of the figures might be interesting. These were picked up hurriedly and it is not possible to check them accurately. For example, all the shop welding on our first two cruisers was checked as a finished weight; that is, the fabricated parts were weighed after welding so that the weight of deposited metal is lost in the weight of steel delivered to the ways. However, there were 14 tons of deposited metal. That means the final deposit, exclusive of stub and splatter loss. I should estimate that at least 30 per cent more was put on in the shop, perhaps even higher than that—say, 20 tons of deposited metal on each of the first two ships.

A check of the storehouse records for wire delivered to the *Indianapolis* shows that to date just short of 100,000 pounds of wire have been delivered to the ship. My own deduction for stub and splatter loss, based on a good many tests in the yard, is not far from 25 per cent. Converting that into tons means that the ship will have somewhere around 32 tons of deposited metal. Anybody's guess is good for the fourth ship, which is practically a sister ship of the *New Orleans*, but my own estimate will be in excess of 55 tons of deposited metal. That is a lot of welding rod and it illustrates, too, the rapid growth over some four or five years even in the Navy's use.

With Captain Gawne's observations in part ten of his paper, I am in thorough and complete agreement. In fact, it is the most interesting part to me, particularly from the standpoint of costs. The training of the people who do your design, the matter of shop assembly and, finally, the accuracy of fitting have a great bearing. It is not always true, though, that the designer has a free rein to do what he knows the welder and the erector want, and there is a case in point on those ships which is worth mentioning, particularly with regard to Mr. Bibber's tests on fillet welds. For example, the longitudinals in the forward part of the ships are built up of a thin web and a heavy face plate. Those two members are welded together. Due to deep frames and bulkheads those longitudinals, of course, are frequently interrupted. Where interrupted the specifications require that the web plate be cut, but that the face plate extend through the bulkhead for at least 12 inches.

That requirement makes a very nice welding job into a Japanese jigsaw problem. It makes it impractical to weld the face plate to the web in the shop because of this protruding end of the face plate which is to be led through a slot in the bulkhead or floor, and requires us to do all that welding overhead in the ship.

Furthermore, the fitting of these comparatively heavy pieces into small slots and later welding up those slots increases cost tremendously. I hope that further investigation of the fillet weld, more particularly of the double tee joint, will permit eventually using a very much simpler connection at these points. The design of a ship, incidentally, is full of those points. That is merely one.

The matter of fitting and its effect on costs is mainly one of view-point. When welding first came into shipbuilding it came in as a repair tool. It made possible very difficult repairs in a minimum of time and cost. In new work construction it saved the job in more cases than one. Alterations in design when material had been partly fabricated made use of welding to reclaim some of that material. Mistakes or poor fits were made good. It was expensive but the expense was justified. When we come to design ng welding on a ship, we have an entirely different matter. If the design calls for a tee joint with a quarter-inch continuous fillet weld, and when those parts are assembled on the ship there is an opening of an eighth of an inch (an eighth of an inch isn't very much to your old-time shipbuilder) that more than doubles the cost of the weld and moreover gives the welder a very difficult job in achieving a neat and workman-like finish.

We must get accustomed to much closer and more accurate fitting. Welding, accused of encouraging sloppy work, is going to be actually the means of getting a higher grade of shipbuilding than we ever had before, simply by necessity.

MR. E. D. DEBES (Bethlehem Shipbuilding Corp., Ltd.): Mr. Chairman and Members: I came down here rather hurriedly and did not have time to make any notes, but I would like to ask Capt. Gawne a few questions: We noticed that the rings in the stern tubes on the *New Orleans* are welded. We had this under consideration in an effort to obtain sound castings, and I assume that was your reason for welding the rings, and that you had to anneal the castings after welding. We also considered leaving the rings out entirely and machining the tubes right through. This, however, has not been finally settled.

CAPTAIN J. O. GAWNE (United States Navy): Putting the welded rings in was a requirement of the Bureau of Construction and Repair and I understand that it was due to a large extent to troubles which they had experienced in getting sound castings with the rings forming a part of the barrel. We have finished that work on all four struts and on four-shaft tube castings successfully. The struts, of course, haven't been annealed; the shaft tube castings have been annealed.

MR. DEBES: I should also like to ask Capt. Gawne if he has any data on the shrinkage caused by welding.

CAPTAIN GAWNE: We have the data on the seaplane wreckage derrick which we built.

MR. DEBES: We have that data, also the data on the garbage lighter built on the West Coast. We have carried out experiments to check the data given in the Navy Department's report on the lighter, but so far our results do not agree in that we get less than half the shrinkage.

CAPTAIN GAWNE: We have taken steps to take careful data on the forward end of a ship when it is welded, but that work hasn't got far enough along to make that data available as yet.

MR. DEBES: Especially on transverse shrinkage we can't get the same results as the West Coast Navy Yard. We are, however, carrying out more elaborate experiments, the results of which will be available in a short time.

CAPTAIN GAWNE: Do you refer to the new cruiser or a barge? It would be interesting to compare data.

MR. DEBES: Our experiments are carried our in connection with the new destroyer to determine the methods to be employed in constructing these vessels, which are of the semi-welded type.

MR. WILLIAM BENNETT (Lloyd's Register of Shipping): Mr. Chairman and Gentlemen: Mr. Holbrook's

very interesting and instructive paper covers a subject which has become of increasing importance during the last decade, and, of course, I am especially interested in it from the classification and insurance standpoint.

For many years classification societies approved autogenous welding with some hesitation and only for relatively unimportant repairs. During the past few years, however, an increasing demand has arisen for the extension of its approval, so that we now find its use sanctioned not only for the welding of bulkheads, non-strength decks, inner bottoms, pillars and girders, casings and deckhouses, etc., but for the welding of the complete ship, provided certain stipulated tests are satisfactorily carried out at the shipyard.

Mention might be made in passing of the all-electrically welded *Fullagar*, now the *Shean*, classed experimentally by Lloyd's Register of Shipping as far back as 1920. The vessel has had very severe service, running first between South Wales and Liverpool with cargoes of steel plates. Later she was taken to the West Coast for coasting service in British Columbia, carrying cement. In 1930 she ran on a rock at full speed, damaging the bow severely. Her record is as follows:

Only on one occasion prior to the damage was the welding required to be renewed. The corrosion on the welded material is not more marked than on the surrounding material. After the above-mentioned damage, it was found that the welding was satisfactorily performing its function as a connecting medium.

It is no wonder, therefore, that rules have now been proposed by Lloyd's Register of Shipping giving directions as to the size of full and light welds, also the size and spacing of intermittent welds, width of overlaps, throat thicknesses of welds and the kinds of welds to be used in the different parts of the vessel's structure, including shell, deck, center girder, inner bottom, bulkheads, frames, beams, etc.

Naturally such progress which has developed so far is to be found in the smaller types of vessels, such as steel deck barges and oil barges. The Holbrook system provides an adequately strong and seaworthy vessel. There is no necessity to reiterate the method of construction, as that is given in full detail in the paper, but in general it may be said that the system comprises primary transverse members in the form of webs, the secondary shell support being provided by the longitudinally disposed flanges of the channel sections. These are all connected as mentioned in the paper, by automatic welding, the advantage of which is obvious as it disposes of errors introduced by the human element. Further, the welding is done on the relatively thick flanges of the channel bars, not on the thin shell plating, thus obviating any local weaving of the shell due to the thermal effects of the welding, as is sometimes associated with other systems of welded construction.

I have no criticism to make on the paper and have no hesitation in endorsing the system of construction as applied in this type of welded vessel. I wish to congratulate Mr. Holbrook not only for his paper but for the excellent barges which I have from time to time seen produced under his supervision at the Federal Shipbuilding and Dry Dock Company's plant.

MR. G. N. BULL (Lincoln Electric Company): Mr. Lincoln was going to present a few comments on Mr. Holbrook's paper. He has asked me to express his regrets at being unable to attend the meeting. I will read a few comments in his behalf.

"The welded barge described by Mr. Holbrook is a very interesting application for some of the newer developments in arc welding. This uses the first automatic machine for ship construction which welds with the shielded arc.

"The importance of this can best be appreciated when it is known that probably within the next five years no type of welding other than the shielded arc will be used. The reason this is true is that with the shielded arc the tensile strength of the weld is increased by about 30 or 40 per cent over the unshielded arc, and also the ductility of the weld is increased by about three times. In other words, the resulting weld is so very much better that, if reliability is considered at all, other types of welding will, of necessity, be superseded.

"The shielded arc is the type of welding wherein the deleterious effects of the nitrogen and oxygen of the air are eliminated in the arc. This can be done by a number of methods, i.e., by gas, by some types of slag coating on the deposited metal, or by a gas which is actually manufactured at the point of weld by the burning of either the coating on the rod or some fibrous materials which are fed to it.

"The machine used by Mr. Holbrook in his manufacture was the first commercial automatic welding machine using the shielded arc. It is still the only type in commercial operation today, yet there is very little doubt that methods will be found so that the metallic arc can also be automatically used and the same shielding results obtained.

"The advantages of the type of welding used in the construction of this barge are numerous. As there is practically no metal added, there is no possibility of laps or breaks in the welded seam, and the total cost of doing the work is infinitesimal compared to previous methods. There is no preparation of the edges necessary, and the welding speed for the size of the weld is several times as fast as can be obtained with other known commercial methods.

"This same type of apparatus and method can be used in many other places where it is not now in commercial operation. Among these will be such places as the welding of battle-deck flooring, the manufacture of any large, flat surface made up of shapes or plates, the manufacture of pipe in all sizes, the manufacture of other types of containers.

"However, this application has already been applied to large water pipe almost universally, and is being used also in the manufacture of smaller diameter pipe and tubing. There is very little doubt that this can commercially be applied to welding of plates up to $^{3}/_{8}$ in. thickness without backing and with full penetration of the sheets under proper conditions.

"Mr. Holbrook's paper not only tells us of a fine example of welded construction which is superior in every degree compared to a wood or riveted design, but at the same time it also shows how automatic machine welding can be applied to produce a superior welded construction at low cost."

Written Discussion by Mr. David Arnott of Mr. Gordon G. Holbrook's Paper on "Welded Barge Construction by the Federal Shipbuilding & Drydock Company."

That the application of electric arc welding to ship construction has become increasingly important in this country in recent years is in no small measure due to the work of pioneers like Mr. Holbrook, of the Federal Shipbuilding & Drydock Company, who were quick to see the possibilities of the all-welded ship and had the necessary courage and initiative to go ahead and convert their theories into practice.

It was obvious from the beginning that a suitable and

immediate field for the successful and economic application of arc welding to shipbuilding lay in the construction of scow barges of simple rectangular section rather than of vessels of ship shape form, and Mr. Holbrook's design was got out primarily for this class of "straight" work in association with the use of the automatic machine. The American Bureau of Shipping, with which classification society I have the honor to be associated, took a keen and sympathetic interest in Mr. Holbrook's proposals right from the early stages of the design, and four of the all-welded barges turned out by the Federal Shipbuilding Company were built under the supervision of our surveyors to the highest classification of the Bureau. I may say that these particular barges have all given very satisfactory service and have more than fulfilled our expectations.

Welded barges are not any more immune from the perils of the sea than their riveted sisters, and it is therefore not surprising that since they left the builders' yard they have been subject to the usual casualties, i.e., grounding, collision, etc.

The Bureau Surveyors who supervised the damage repairs are of the opinion that in each case the damage resulting from the casualty was less extensive and easier to repair than would have been the case if the barges had been built of the usual riveted construction. There were no leaks or failures of the weld adjacent to the actual area of contact, and repairs were very easily and economically effected by cutting away the damaged portion only and welding in new sections; no other renewals were necessary, nor were any major repairs required to the adjacent structure. Had the vessels been of the ordinary riveted plate construction, it is probable that considerable caulking and rivet renewals over a wide area in the vicinity of the actual area of contact with the ground would have been necessary. There is no doubt that all-welded steel barges have come to stay, and if Mr. Holbrook is not over-optimistic in his statement that welded barges can now be built at a price to compete with riveted barges of conventional design or even with wooden barges, the time when welded barges will be in general use is not far distant.

Discussion of paper by Leon Bibber, on "Experimental Determination of the Values of Fillet Welds in Tension," by Cyril D. Jensen.

Mr. Bibber makes two assertions in his paper to which exception is taken. First, in computing for working ultimate loads he considers a fillet weld to have penetration as indicated in Fig. 1*A*. He considers this an important part of his general computation for working loads and states that the strength of fillet welds should be based on this feature, that is, an additional $^1/_{16}$-in. penetration into the root. From my own experience, which includes observation of a great many specimens broken in our laboratory and also etching of many more to study penetration due to arc length and welding current, I have come to the conclusion that penetration similar to Fig. 1*A* is rather the exception. For the general acceptable weld I suggest Fig. 1*B* as representing more nearly the average penetration for bare-wire welds. Very often mediocre welders get a penetration as indicated in Fig. 1*C*.

Fig. 1

The second item is that Mr. Bibber feels that the series of tests made by him and reported at the spring meeting proves the correctness of his theory of stress distribution in end-fielded fillets.

Using his tests, but computing stresses by the present accepted method, namely, P/throat area, there results an average stress for the $^3/_8$- to $1^1/_4$-in. welds of 43,800 lb. per sq. in. with extreme values of 37,000 and 52,400 lb. per sq. in. Considering the fact that it is already known that brittle metal results from bare-wire welding and also that for working loads unequal distribution of stress obtains across a fillet, the average stress of 43,800 lb. per sq. in. seems very reasonable.

This criticism of Mr. Bibber's presentation may seem to indicate that I am championing the present method of computing stresses in end-welded fillets. My view-point is that the present method is extensively used with apparent satisfaction and should not be given up unless a more perfect method is evolved and is definitely proved true.

WEDNESDAY AFTERNOON SESSION

Pres. F. P. McKibben Presiding

Discussion of paper on "A Study of the Transformation Points of Fusion Weld Metal,"* by Messrs. Hensel and Larsen of the Research Laboratories of the Westinghouse Elec. & Mfg. Company, presented by Mr. Larsen.

MR. DOYLE: Mr. President, I would like to ask the author a question. He referred to the nitriding of Armco iron and the nitriding of bare-wire weld. We are more or less familiar with the so-called nitriding of steels which I believe are supposed to contain a specified percentage of aluminum or chromium or some other alloy. But what I would like to ask is, if Armco iron can be nitrided is there any reason why it should be nitrided other than for experimental purposes? Is there any commercial reason why it would improve it for use?

MR. E. I. LARSEN (Westinghouse Elec. & Mfg. Co.): No, it will not improve it. In fact, nitrided Armco iron is extremely brittle and if heated or given a slight tap will break all to pieces. We merely nitrided these samples to get the nitrogen in the iron for testing purposes. We knew that welds contained nitrogen and we wanted to see if we could prove that nitrogen in the weld material was causing these peculiar expansion characteristics. In order to get a higher nitrogen content we nitrided the weld material which contained between 0.14 and 0.17 nitrogen and in that way we got samples containing as much as 3.5 per cent nitrogen. As far as I know there are no commercial applications for nitrided Armco iron.

MR. MCCUNE: How far does that nitriding process go, much below the skin?

MR. LARSEN: We drilled these samples. That is, we took a half-inch sample and drilled a quarter-inch hole through it so the stream of ammonia passing over the sample would also pass through it, and nitride on the inside as well as the outside. We usually got cases of about a sixteenth of an inch thick during a week's nitriding, but during that week's nitriding we would raise the temperature to 900 degrees every 24 hours in order to diffuse the nitrogen into the material. In that way we obtained fairly homogeneous alloys.

MR. W. B. MILLER (Union Carbide and Carbon Res. Labs.): In Table II the oxygen content of a bare-wire weld is given as 0.259%. Calculated as iron oxide this

* Paper published in April issue of JOURNAL OF THE AMERICAN WELDING SOCIETY.

gives about 1%. This same table shows the coated electrode weld to contain considerably less oxygen and nitrogen, whereas in Table III the residue analysis shows the coated electrode weld to contain approximately three times the amount of impurities found in the bare-wire weld. Since FeO is not determined by residue analysis, we believe that the gas analysis results are to be considered a more reliable index as to the amount of impurities in the weld metal.

MR. LARSEN: We obtained the residue analyses by the method developed by Fitterer, that is, by electrolysis of the samples. The FeO content cannot be determined by this method.

MR. MILLER: I should say that Table II tells the better story.

Discussion of paper on "Cause and Cure of Intergranular Corrosion in Austenitic Steels,"* by Dr. John A. Mathews, Vice-President of the Crucible Steel Company and also Director of Research.

DR. R. H. ABORN (United States Steel Corporation Research Laboratory): Dr. Mathews' very able presentation of his subject brings out with welcome clarity and straightforwardness much of the knowledge which has been all too often shrouded in undue mystery. There is, however, in our opinion, a certain unwarranted indefiniteness still attaching to a few points discussed by Dr. Mathews.

In the first place, his remarks on the chromium depletion explanation or hypothesis seem to call for a brief reply, since possibly we have been the most vigorous supporters of this hypothesis on this side of the Atlantic. Dr. Mathews mentioned a very striking example of an analysis of disintegrated metal showing that the full carbon content was apparently present. That to us is not surprising; the proponents of this theory have never assumed that any appreciable proportion of the carbon would have to precipitate at the grain boundaries in order to induce serious local chromium depletion. Indeed, the loss in weight suffered by the whole of a disintegrated piece of metal is far too small to account for any appreciable loss of carbon or chromium considered as a fraction of the whole, and therefore it is not surprising that analysis does not disclose the possible ten-thousandths of a per cent loss in carbon.

Dr. Mathews has implied that chromium and carbon apparently diffuse at the same rate when carbide precipitation takes place at the grain boundary. That viewpoint, we believe, may be shown untenable by a consideration of the processes of carburizing and chromizing. Although they are generally not done at the same temperature, yet it is well known, I believe, that the process of carburizing is a very much more rapid process than that of chromizing even at temperatures which are considerably higher than the temperatures involved in this particular phenomenon. Therefore it is not surprising that with temperatures below 1500° F. and generally in the vicinity of 1200° F. (or below) this phenomenon can occur with carbide formation at the expense of chromium depletion in the immediate vicinity of the grain boundaries. A simple computation will show that the formation of any crystallite of Cr_4C in 18–8 requires the migration of carbon from distances between two and three times as remote as that of the chromium in the same period of time.

Higher chromium steels, as Dr. Mathews stated, show a susceptibility to intergranular attack, similar to that evidenced by lower chromium of the ordinary 18–8 variety. That, too, is to be expected since this disparity in rates of diffusion of the chromium and the carbon is not appreciably altered by merely adding 10 per cent or more of chromium. Since the chromium-rich carbide contains, as has been variously estimated, from 75 to 90 per cent of chromium, we would not expect to find, *per se*, any improvement in this respect until we increase the chromium content of the alloy certainly well above 50 per cent, but obviously such alloys are not listed among the commercial metals and have not been much investigated.

Dr. Mathews also stated that tests over very long periods in the range of 1000–1500° F. do not seem to bring about a correction of this susceptibility, at least to any marked degree. In the following table are summarized some data that we have obtained at the laboratory on 18–8 alloys containing 0.06–0.08 per cent carbon showing the effect of time of exposure on the temperature at which maximum susceptibility develops and on the highest temperature at which susceptibility can be detected.

Period of Exposure	Approximate Temp. of Max. Susceptibility	Highest Temperature of Susceptibility
	° F.	° F.
2 minutes	1300	1500
1 hour	1200	1400
100 hours	1100	1300
1000 hours	1000	1200
4000 hours	950	1100

As determined by $CuSO_4$:H_2SO_4 test

The trend toward lower temperatures with longer period of exposure is clearly evident and demonstrates in a convincing manner the influence of prolonging the exposure to a given temperature on the restoration of chromium in the depleted areas through diffusion. Thus at 1300° F. while chromium depletion is very marked after 2 minutes, restoration is practically complete after 100 hours at the same temperature. It is not surprising then that Dr. Mathews has observed that after 2500 hours the 18–8 is still susceptible to attack at 1000° F. simply because this gradual lowering of the upper limit of the temperature range of susceptibility never passes 1000° F., as far as we have observed in test periods up to 4000 hours.

One further point raised by Dr. Mathews was in regard to the size of the carbide particles themselves. It does not seem that the size should affect the chromium depletion, but the requirements for the formation of a large particle involve either a long time at a given temperature or a shorter time at a higher temperature. Now either of these conditions, in the meantime, is ample for chromium diffusion to occur and make up for the depletion in the immediate vicinity of the grain boundaries.

We should like to add a few sentences to Dr. Mathews' discussion of the three methods of eliminating intergranular corrosion. First, the use of low-carbon metal is indeed greatly superior, and that degree of superiority is no longer a matter of conjecture; one can easily measure the precise degree of improvement resulting from the use of the low-carbon alloy by a method developed in the Research Laboratory of the Steel Corporation involving the measurement of the electrical resistance of a specimen before and after a controlled intergranular corrosion attack. The method has been described in a paper recently presented before the American Institute of Mining Engineers.

In regard to the proposal to increase the alloy content, it is indeed a pleasure to note that Dr. Mathews also has

* Paper published in April issue of JOURNAL OF THE AMERICAN WELDING SOCIETY.

observed that the mythical point of demarcation at an iron content of 72.5 per cent is without significance in the behavior of these alloys toward intergranular corrosion. We fully agree with Dr. Mathews that there is no basis in fact for that opinion; many specimens with more iron have given excellent service and many more with less iron have suffered severe intergranular attack.

As to the remark that the exact explanation of the efficacy of titanium has not yet been found, we believe that a satisfactory explanation is not so difficult as it may appear. In fact, it becomes relatively simple from the viewpoint of the chromium impoverishment concept. The titanium action involves substantially the formation of titanium carbide, instead of chromium carbide, thereby avoiding chromium depletion. With the exception of silicon (the benefits from which are solely due to the formation of ferrite) all of the special elements mentioned by Dr. Mathews form carbides more stable than chromium carbide. As titanium is very effective we have given it particular attention, involving the development of the proper proportions in which it should be used and a thorough study of the properties of these titanium steels. The ability of titanium to produce a stabilized alloy without the accompaniment of ferrite is noteworthy in that it provides a means of retaining substantially unaltered all of the valuable physical and mechanical properties of the original austenite. We believe that titanium offers a very satisfactory method of avoiding intergranular corrosion in many applications where that problem exists.

In conclusion, I believe it must be admitted that the real test of an explanation is "Does it work?" Is it of any practical value in predicting the behavior, and, by suitable alteration in processing based on this hypothesis, producing a material which is substantially free from this susceptibility? We believe that the chromium-depletion hypothesis is a workable one and does explain the behavior, inasmuch as entirely apart from chemical addition elements we have produced an alloy which is substantially free from this susceptibility to intergranular attack, through a means of inducing carbides to precipitate uniformly throughout the grains so that the paths of diffusion are reduced in length by a thousandfold or more. Consequently, chromium depletion is practically negligible and therefore the material is substantially immune to attack. This actually has been achieved by experimental methods with the production of material which in practice has fully justified the use of the chromium-depletion hypothesis in working out the method of production.

Dr. John A. Mathews (Crucible Steel Company of America): You can produce a magnetic condition containing some ferrite without the use of an additional element, but in those cases, while we may have some resistance to intergranular attack, we have not anywhere near the resistance we have had when the additional element is present. The additional element is not the only way to produce delta ferrite in chrome-nickel series if you balance the chrome-nickel properly.

On the other hand, in a relatively low type, around 18–8, when you have magnetism, it is probably due to the breakdown of austenite into ferrite with the chrome impoverishment and in that case magnetism may indicate susceptibility.

Bear in mind the samples we were working with and discussing here had to do with short-time heating as, for example, in the process of welding sheets or plates, and do not include the holding of these alloys for very long periods of time at embrittling temperatures as might be true in chemical apparatus where steel is continuously used within a range of 1000° to 1200° F., for example.

In this table that Dr. Aborn first put on the board, do I understand that 1100° was the lowest temperature at which he found susceptibility?

Dr. Aborn: I believe I said that for a thousand hours the maximum susceptibility occurred at about 1100° F. but that in certain alloys we had found some susceptibility to attack below 900° F.

Dr. Mathews: A sample we recently examined after 2500 hours at a thousand degrees was markedly susceptible. The point I was getting at was that the minimum point was at about a thousand, but apparently after several thousand hours it was still susceptible, and homogeneity by diffusion had not been reached.

Most of the work I have been describing was for a constant time within that range. The ten-minute period we took as representing what might happen in the ordinary welding operation.

Mr. Miller: I should like to ask Dr. Mathews and Dr. Aborn if all their corrosion experiments were on fully annealed material to start with, or on material with commercial finish, i.e., somewhat cold-worked? Is there any difference in the effect of the welding heat on fully softened or cold-rolled material?

Dr. Mathews: We have found that the cold-rolled stuff in general is quite resistant to corrosion where the stressing is uniformly applied, but where a right-angle bend is put into a piece, it is likely to fail at the bend more readily than in flat portions where there are no unusual stresses.

Mr. Miller: What I mean is, is there any difference in the effect of heating at, say, 1200, on cold-rolled material on the susceptibility?

Dr. Mathews: Cold-rolled material has presumably had the high anneal at some time before the cold-rolling operation and I am inclined to think it would be quite upset by reheating at 1200.

Mr. Miller: I had in mind cold-worked material would be more susceptible to carbide precipitation than the fully annealed at the same temperature.

Dr. Mathews: I have no figures on that.

Dr. Aborn: I think definitely that the cold-rolled material is distinctly less susceptible.

Question: I would like to ask Dr. Mathews if he found the addition of titanium in the higher carbons to be effective in resisting corrosion.

Dr. Mathews: The author greatly appreciates the discussion by Dr. Aborn and would not wish to convey the impression that he disagreed with the hypothesis of Mr. Bain and Dr. Aborn in regard to chromium carbide precipitation or chromium impoverishment. He feels, however, that something remains to be explained in regard to this phenomenon. There can be little question but that chromium carbide precipitation does occur. Some people believe that there is a migration of the carbon to the grain boundaries and that the precipitation there is much greater in amount than that due to actual carbon in close proximity to the grain boundaries at the time that the action occurs. If there is a migration of carbon from the center of the grains to the peripheries and this intergranular material is subject to attack, then the residual granular material such as we analyzed would be expected to show this loss of carbon and if such migration does not take place then the effect at the grain boundaries must be considered as due to the "one-hundredth of 0.15 carbon," for example, as referred to in Dr. Aborn's discussion. This, it would be recognized, is an extremely small amount of carbon to produce such disastrous results as are sometimes noted. Furthermore, if the period from 2 to 10 minutes at a temperature of, say, 1200° F. is sufficient to cause this trouble, then it would certainly seem as though 2500 hours at 1000° F.

should be a sufficiently long time to bring about a uniform diffusion of chromium in the areas surrounding the carbides.

THURSDAY MORNING SESSION

April 28, 1932

Mr. C. W. Obert, Chairman, Welding Conference Committee, Presiding

Discussion of paper on "Spot Welding,"* by Carl De Ganahl, President, Fleetwings, Inc.

CHAIRMAN OBERT: The paper is now open for discussion. Is there any question you would like to ask Mr. De Ganahl about this very interesting practice? I consider this a very important and valuable contribution to the records of the AMERICAN WELDING SOCIETY. These alloys embrace a large family and much too little is known of them. We need to know a great deal more, particularly in connection with their welding properties, and Mr. De Ganahl has really done us a great favor in presenting us this record.

MR. C. E. HEITMAN (E. G. Budd Manufacturing Company): I should like to ask Mr. De Ganahl if he uses a mechanical timer in conjunction with the clapper switch on these loads.

MR. C. DE GANAHL (Fleetwings, Inc.): We have never been able to get any kind of accuracy at all with a magnetic timer. We have been forced to use the mechanical timer.

MR. HEITMAN: We have tried the mechanical timer in conjunction with a clapper switch and find time variations we get on a very short interval of time.

MR. DE GANAHL: We had a lot of trouble with clapper switches at first and found it necessary in our case to use two switches, one to make contact and the other to break it. We found the bounce in an ordinary clapper switch was too great for reliable contact.

MR. HEITMAN: Especially with A. C. current.

MR. DE GANAHL: You mean using a magnetic contactor. We don't use a magnetic contactor. In the magnetic contactors the accuracy is of the order of three to four cycles. I don't know whether there are any better ones about.

MR. HEITMAN: Of course, that is with alternating current. With direct current you probably get better results.

MR. DE GANAHL: We haven't tried the D. C.

MR. W. R. HAINSWORTH (Electrolux Servel Lab.): I was very much interested in this sentence which reads: "The reason the same area of corrosive metal does not occur around a spot weld is because the heating and cooling are so extremely rapid that the carbon has no time to come out of solution."

It has been our experience in connection with the manufacture of the Electrolux refrigerator while using stainless steel in a dilution flue, that is, a flue extension on the boiler where the gases coming through the boiler are brought in contact with air and diluted, that we have an extremely severe condition as far as corrosion is concerned. Water condenses out of the flue gases and acids are present due to the carbon dioxide and sulphur dioxide in the gas. Using a straight weld, acetylene weld, on an 18–8 alloy, always resulted in an area or strip about half an inch wide inside the weld which would rust very badly in a comparatively short period of time.

Then we went over to spot welding, not because we thought we would get away from rusting, but on a cost basis, and we were very pleased to note that the rusting and corrosion almost entirely cleared up and this ties in very nicely with the statement regarding the reason for this particular condition.

Discussion of paper on "Production Welding of Light Gage Metal Specialties,"* by Messrs. W. R. Campbell & R. S. Taylor, of Servel, Inc., and presented by Dr. William R. Hainsworth of the New York Laboratory of Servel, Inc.

MR. DALE SPOOR: In the testing of the weld in roughly what percentage of units do you find leaks?

DR. HAINSWORTH: The unit is tested and leaks repaired before it comes off the line. So when it comes off the line there are practically no leaks. In the first test 50 per cent of the units may have leaks in one or more welds. These leaks are then welded and pressure is added again and it passes through two or three successions of welding and testing. The final job, of course, goes out without leaks.

MR. SPOOR: You mention you tested with a 950- or a 1000-pound air pressure. Do you find there is any danger of hydrogen at about 200 pounds' pressure leaking through a hole that air wouldn't leak through at a thousand pounds?

DR. HAINSWORTH: No, we found a 1000-pound air pressure test quite adequate in protecting against hydrogen leaks. It is a strange thing about these very small leaks—we studied them to some extent and we found in some cases a small leak would seal itself. In other cases it would open up. However, hydrogen is held in pretty well when the unit is tight to a 1000 pounds of air.

CHAIRMAN OBERT: Doctor, may I ask with regard to that box; is that removed when it goes into the refrigerator?

DR. HAINSWORTH: That is just for testing purposes. It is a box having a known heat leakage and a known quantity of heat is added to the freezing element inside that box and with these known quantities if the unit will pull the temperature down to a certain point, why then the unit must have a certain capacity.

MR. GRUNOW: You don't give these units a hydrostatic test before you give them 900 pounds of air, do you?

DR. HAINSWORTH: It would be rather difficult to do that because it would be hard to clear out all the water that is in the system. There are so many turns and small pockets, it would be almost impossible to remove that water before charging and naturally that would throw in a considerable irregularity in the charge. The charge has to be a certain amount at a certain concentration and if water is in the unit before charging the concentration would be very much disturbed.

MR. GRUNOW: Do you find any leaks after they get into the field due to cooling and heating in service? Any trouble in that way?

DR. HAINSWORTH: It is obvious that with a device of this nature made in high production it would be impossible to keep all leaks out; that is, to make the units 100 per cent tight. We have occasionally a unit which gets out with a leak in it and it will show up in the course of a month or two. In other words, if there is a leak it will come back in a comparatively short time. After that the unit will operate indefinitely.

MR. E. WALKER: Are all units returned to the shop for service or do you make them in the field?

* Published in April issue of JOURNAL OF THE AMERICAN WELDING SOCIETY.

* Paper published in April issue of JOURNAL OF THE AMERICAN WELDING SOCIETY.

DR. HAINSWORTH: The unit is returned complete to the shop for repairs.

MR. GRUNOW: In studies of these leaks, have you made an attempt to classify the causes of those leaks—a certain percentage due to raw material, defects in the tubing, etc.?

DR. HAINSWORTH: That has been studied to a considerable extent. We do have some leaks occurring because the tubing does not come up to certain specifications. We try to specify hardness and analysis and control it in that way, but in spite of that type of control we still occasionally run into difficulties and we find that sometimes a leak will occur due to distortion or splitting in the galvanizing bath.

However, our major trouble is in connection with the new welders, bringing in a new man and putting him to work. He has to start out some time, to weld, of course, and during the initial training period he is inclined to be a little, not exactly, careless, but he isn't skillful enough to make the weld absolutely tight.

MR. GRUNOW: Are most of the welds on that unit, aside from the cabinet itself, butt welds or lap welds?

DR. HAINSWORTH: They are mostly butt welds. There are a number of welds, however, where the tube actually projects inside the chamber to which it is connected. This tube, for example, projects in here a little way. The pump pipe projects into the boiler a little way. There are both types occurring in the unit.

CHAIRMAN OBERT: One thing that appeals to me, Doctor, is that you show a remarkable freedom of complications with the gas hose hanging from your overhead receptacle. On a line production proposition, it would be natural to expect a tremendous complication.

DR. HAINSWORTH: Of course, the acetylene and oxygen are supplied through pipes which are perhaps eight feet off the ground and pass along just to one side of the conveyor, and the torches are automatic. The operators hang the torch up on a little lever controlling the gas valves. There is a little pilot light from which to light their torches. They seem to be able to manipulate the torches and the tubing without any trouble. I myself expect, in passing through the plant, to see a lot of these fellows getting burned. The operators are just a few feet apart and all the tubing apparently very much mixed up, but if you study it a little while it seems to be quite orderly and there are surprisingly few cases of burns.

MR. WALKER: In your heat-absorbing capacities what factors do you find in manufacturing that will decrease the heat-absorbing capacity of the unit?

DR. HAINSWORTH: Well, that is rather a hard question to answer. Many times we wish we knew the answer to that particular question. To get into the theory of the unit a little bit, you will see that certain relationships of pipe sizes and resistance to gas flow must be maintained and the actual pressure differences which you have to work with inside the unit, to cause the circulation of the gases or to cause the liquid to circulate, are extremely small. The circulation of gas between the evaporator and absorber is simply due to the difference in weight of a mixture of ammonia and hydrogen which is relatively high in ammonia, and the mixture of ammonia and hydrogen which is relatively high in hydrogen. The difference in weight of these two columns of gas causes the gas to circulate. So we must know very definitely what the resistance to gas flow is in that circuit.

The resistance in this particular unit, for example, with gas flowing around through the absorber, through the exchanger and back through the evaporator, is in the neighborhood of one-tenth of an inch of water pressure and that must be accurately controlled because if the gas circulates too fast a lot of hydrogen is heated and cooled unnecessarily and the efficiency drops. If it circulates too slowly enough ammonia to produce the refrigerating capacity cannot be picked up. If we have any section where the weld is partially plugged or the resistance has been changed, due to some operation in the subassembly, that will affect capacity. Also the charging of the unit affects the operation.

MR. WALKER: I was wondering if the distortion when the heat strain is taken off it in any way affects the operation of it—if that lowers the capacity much.

DR. HAINSWORTH: Changes in dimensions will lower the capacity. There must be a certain relationship between the pump pipe delivery point and the liquid level in the absorber and the point where the ammonia solution is delivered to the absorber, but these are taken care of by placing the unit in a final straightening fixture. The unit cannot go into the fixture until the relative dimensions are correct.

MR. WALKER: How much do you allow for raising and lowering that particular unit in there to affect your capacity below what is required? Any particular height allowed for that suction in taking off the heat strain?

DR. HAINSWORTH: The allowance as far as dimensions are concerned is fairly small. We hold the machine to certain fixed dimensions which must be within a thirty-second of an inch in most places. I don't know whether I have your question exactly in mind. Are you speaking of dimensions of the various parts?

MR. WALKER: Yes.

DR. HAINSWORTH: I would say that in certain places the dimensions must be maintained within a thirty-second of an inch in order not to affect the operation of the unit. This may sound like quite a bit to you in comparison with the limits on a compression type machine, where a piston operates in a cylinder, but in view of the type of welding construction used these limits are not so easy to hold.

Discussion of paper on "The Welding of Extruded Metal,"* by I. T. Hook, of the American Brass Company.

MR. CROWE: I would like to ask Mr. Hook if he finds it practical to weld sections such as the first section he passed around, the complicated section.

Also another question as to whether he has found the neutral flame better than a slightly carburizing flame for making such a weld.

The third question, if I may: If you start with a filler metal of the same composition as the parent metal in making a weld of a complicated section do you wind up with the same color?

MR. HOOK: In answering the first question, which was to the effect as to whether it would be practical to weld a section of this sort,† I would say the best method of making a weld of that character would be from the back. In that case we need not finish off the weld metal and we perhaps would not need to close the entire seam. If we weld it from the back, the two parts would be drawn together so closely that the front could be finished off with almost no hairline visible.

The second question was whether we used a neutral flame. I would say that a slightly oxidizing flame is better than a reducing flame for this reason: The slightly oxidizing flame will produce a coating of zinc oxide on the

* Paper published in April issue of JOURNAL OF THE AMERICAN WELDING SOCIETY.

† A 6-in. wide extruded shape having a very irregular right section. The shape was brought in for illustrative purposes.

molten metal and thereby protect it from further oxidation. That sounds paradoxical but it is true and you will find that such a condition will work.

However, we do not advocate the use of an oxidizing flame as a rule. It is somewhat dangerous practice for the average welder. He is used to the neutral flame and we may as well let him use it. We get very nearly the same condition if we keep the weld metal at least three-eighths to a half-inch in front of the white cone of the torch, because while one might say that we have in that outer envelope hydrogen, water vapor, carbon monoxide and carbon dioxide, all of which are more or less neutral, nevertheless when these gases are presented to hot metal the effect is slightly oxidizing because the water vapor will be reduced and probably the carbon dioxide will also be reduced and there may a little oxygen from the air swoop in; so that one does get a slightly oxidizing condition. It is very mild but that is what it is.

A fusion weld carefully done will give exactly the same color as that in the base metal. We had a sample come in from the Midwest just a week or two ago in which the weld metal had a distinct greenish cast and quite different in color from the base metal. The base metal was this material, Extruded Architectural Bronze, and the company that sent it in registered a complaint saying that the weld metal which we recommended did not match in color the base metal. We took some of the same weld metal which we had recommended, deposited it on the base metal which was sent in and attained an exact color match.

What had happened? The welder in laying down his weld metal had burned out some of the zinc, possibly as much as two to four per cent of the zinc, so that his weld metal was that much less in zinc than the base metal and when we have zinc of the order of 42 per cent or thereabouts, the color changes rather rapidly with small changes in zinc. We can get a reddish blush of copper on the yellow bronze with just a change of one or two per cent in the copper content, and therefore the zinc content, and we can get a different shade of yellow by the addition of slightly more zinc.

MR. A. K. SEEMANN (Linde Air Products Company): The welding of extruded bronze has occupied the attention of many during the past several years, but uniformly good results are not obtainable without some knowledge of the alloys and their characteristics. The modern architectural trend toward the liberal use of the extruded bronzes and white metals has created a demand for modern joinery as exemplified by welding, and Mr. Hook's paper, therefore, is of especial value at this time. Because the fundamentals are adequately presented, any discussion must necessarily confine itself to the enlargement of certain features.

Our field experiences have for the most part centered on the high zinc, leaded brasses, such as Anaconda Architectural Bronze. We found that neutral flame welding was not entirely satisfactory because of the tendency to form blowholes which showed up only too plainly on the dressed and polished surface.

Our laboratories studied the problem and found that a technique which had for its most important feature a heavy oxidizing flame gave very satisfactory results. The oxidizing flame accelerates the formation of zinc oxide which acts as a protective coating during welding. Mr. Hook has mentioned this characteristic as follows:

"The zinc oxide if allowed to form on the surface of the molten metal will in a large measure protect it from further oxidation until the weld metal becomes overheated." And in an earlier paragraph advises, "The oxide coating should be given greater consideration by the welder than it has."

It is not sufficient, however, to merely use an oxidizing flame of certain adjustment because the zinc oxide formed will become sufficiently heated to volatilize and thus be driven from the metal in substantial quantities.

Of importance are the flux, rod, tip size and blowpipe manipulation. Each of these factors will now be enlarged upon.

Flame Adjustment.—First, adjust to neutral, then reduce the acetylene supply and it will be noticed that the flame at first shortens gradually. As the acetylene is further reduced the flame increases in length but loses most of its luminosity. This is the required flame.

Flux.—It is necessary to use a good flux which will melt and remain molten during the entire welding operation. We have found it advisable to apply flux to the upper and under surfaces to be welded as well as the filler rod.

Welding Rod.—No great trouble has been experienced in obtaining a good color match, although it has been necessary at times to use strips of the parent metal as filler rod.

Tip Size.—The oxidizing flame has a much lower flame temperature than a neutral flame and it is therefore necessary to use a larger tip size. It has been found that a tip two sizes larger than that used for neutral flame welding makes up for the heat deficiency of the oxidizing flame.

Blowpipe Manipulation.—In general use the conventional technique employed in welding steel. The flame should be held quite close to the metal, care being exercised to prevent overheating. Boiling may be caused either by overheating or by a flame not sufficiently oxidizing. Decreasing the acetylene supply will usually correct this condition.

Where introduced this method has produced sound dense welds of good strength and color match. Usually the weld is not distinguishable when polished. Nickel silver when welded by this method has also proved entirely satisfactory.

MR. E. VOM STEEG, JR. (General Electric Co.): I would like to ask a question. Has any experimenting been done using electro-brazing equipment on this extruded metal?

MR. HOOK: I don't believe so. Perhaps some one has tried it but if they have I didn't know about it. We haven't had a transformer that we could use for that purpose and so we have never tried it ourselves. I don't see why it couldn't be done, however.

MR. CROWE: Mr. Chairman, will Mr. Vom Steeg explain what he means by electro-brazing process?

MR. VOM STEEG: That is the resistance method where the low-voltage secondary of the transformer is used to heat a pair of carbon blocks between which the metal is placed and heated in that manner by contact using the ordinary silver solders and fluxes between the pieces to be joined.

FRIDAY MORNING SESSION

J. J. Crowe, Director, American Welding Society, Presiding

Discussion on Paper "Machine Gas Welding,"* by J. L. Anderson, Air Reduction Company.

MR. E. A. DOYLE (Linde Air Products Co.): What is the average comparison of speed in hand welding to machine welding?

* Paper published in June issue of JOURNAL OF THE AMERICAN WELDING SOCIETY.

MR. ANDERSON: On a given thickness of metal I think it is reasonable to say that the ratio between the hand-welding speed and the machine-welding speed may be 20 to one or greater with the present-day experience in machine welding. That doesn't hold with all kinds of welding, but in the case of a straight seam weld that is a conservative figure.

MR. DOYLE: That applies to the light gage materials.

MR. ANDERSON: Material we will say up to three-sixteenths of an inch in thickness.

CHAIRMAN CROWE: I wonder if Mr. Anderson could give some idea of what speeds are being obtained by mechanical welding—just a few examples.

MR. ANDERSON: In the lighter gages, for instance, we will take 16-gage material, which is the thickness generally encountered in machine welding, speeds up to 20 or more feet per minute are quite common in machine gas welding. In lighter thicknesses, even greater speeds. Twenty gage, 26 or 30 feet a minute is being carried on in production. In heavier gages under somewhat special conditions we will say, for instance, in 10-gage material speeds up to 36 feet a minute are being obtained by the utilization of supplementary heat for preheating. In the case, 10-gage material without preheating, without any effort to conserve oxygen and acetylene, welding speeds of 10 feet a minute are being obtained. I am speaking about welds which have the full strength of the parent material. There is one operation going on at the present time on 16-, 14- and 12-gage material where the weld strength is extremely high, fiber stresses of 90,000 pounds per square inch being quite common.

MR. HOBART: May I ask Mr. Anderson what the object of preheating was, was it to increase the speed?

MR. ANDERSON: The object of preheating is to increase the speed and to reduce the cost of the operation by conserving the oxygen and acetylene used in the welding operation. In other words, it is possible with the utilization of supplementary heating at a cost which will average around 40 cents an hour to weld five times as fast with a given quantity of oxygen and acetylene, making the welding operation therefore extremely economical.

MR. DOYLE: I should like to ask one more question. In mechanical welding of gages, say, from 12 to 20, which we were discussing just now, is it not customary to weld them without the addition of filler metal, simply by butting the edges together?

MR. ANDERSON: That is true in the case of a formed material. In other words, material that is not just flat sheets. In the case of flat-sheet welding, it is done both ways—by simply fusing the edges together and by adding material. The higher speed, of course, is obtained by welding without adding material and that operation is always carried on in conjunction with a certain amount of mechanical pressure in order to force the edges together and work the plastic metal.

Under those conditions it is possible to apply much greater quantities of heat than can be applied in an ordinary seam-welding operation.

When I speak of greater quantities of heat, I mean four or five times as much heat, or, in other words, burning four or five times as much oxygen and acetylene per hour as is possible with the ordinary welding operation where a mechanical pressure is not employed to force the edges together.

MR. J. GESCHELIN (Automotive Industries): I don't know very much about machine gas welding and I was wondering what its applications are, if any, in the automotive industry and to what extent it has been used; on what kind of parts it might be used and what its potentialities might be.

MR. ANDERSON: Perhaps the greatest application of machine gas welding today is in the production of tubing for automotive purposes. There is hardly an automobile made today that doesn't employ gas-welded tubing in some form. That may mean a chassis or it may be in connection with the engine or any one of a great number of different uses. Perhaps the most striking example of the use of a gas-welded tube is in the present-day drive shaft between the engine and the rear wheels. Perhaps the greatest proportion of automobiles made this year will be driven by gas-welded tubular drive shafts.

There you have a machine-made weld which has to stand not only ordinary driving stresses but stresses that the green driver puts upon it by letting in his clutch as the engine races repeatedly without failure, and the gas-welded tubing made for that purpose is a very high grade tube, a very high strength tube. In fact that was the part to which I referred when I said that fiber stresses up to 90,000 pounds per square inch were being developed in the weld.

Machine welding does not lend itself to every type of product used in automotive industry because of the great cost for jigs and fixtures and a great many parts are made by hand welding that could be made by machine welding very satisfactorily and more economically if the first cost were not so great. As a rule manufacturers are not yet alive to the point where they are willing to consider machine gas welding on the same plane that some other production methods are considered.

The advantage of the machine gas weld is great strength, ductility, largely brought about by the plastic working of the metal, and that is accomplished partly by taking advantage of the expansion of the metal in the seam edges which are mechanically forced together. The movement of the metal can be controlled by the application of heat to such an extent that a considerable upset is secured without any mechanical movement of the metal.

Perhaps I might explain it this way: While it is possible to control the movement of the edges in the ordinary heat application by correct design of the holding members, it is also possible to exert a considerable edge pressure by the application of the flame in such a way that controlled expansion over a considerable area is produced that will take the place of mechanical movement when mechanical movement may be impossible.

PROF. C. D. JENSEN (Lehigh University): I have a question I would like to ask and that is to find out whether or not you are making pressure tanks under the new specifications of the Boiler Code Committee of the American Society of Mechanical Engineers. They have rather rigid requirements and I am curious to know whether or not your automatic process has been perfected to such an extent that you can fulfil the requirements.

MR. ANDERSON: My idea of that type of weld made for that purpose would be a weld which was not heavily reinforced and therefore might have a sufficient ductility to meet the requirements. Our experience with the gas weld is that almost any desired result can be attained if the set-up is right for it. That has been shown, we will say, in automotive work where very special efforts were made to accomplish results which produced a weld and a product which was uniform throughout the entire circumference of the cylinder.

Again I say I don't know of any concern that has as yet attempted to weld tanks under those specifications.

CHAIRMAN CROWE: If there are no other questions we will proceed to the third paper of the morning session.

Discussion of paper on "Pipe Welding for a High Pressure Steam Power Plant,"* by E. B. Severs and W. P. Gavit of the United Engineers and Constructors, Inc.

MR. T. W. GREENE (Linde Air Products Co.): In regard to the question raised of ferrules to be used on the inside of pipe, mentioned in the A. S. A. Pressure Piping Code, these were referred to in the Code primarily to permit their use to assure penetration to the bottom of the joint for long gas lines. To my knowledge I do not believe ferrules have been used in power lines.

As Mr. Gavit pointed out, penetration to the bottom of this thick wall pipe was assured by carefully going around with the first bead before building up the weld in making the joint.

One factor that I do not believe is generally appreciated is the importance of this installation. I would like to take this opportunity to express to Mr. Gavit and his company congratulations on their resourcefulness and their pioneering in this important installation. This installation, combining extremely high temperatures and pressures, is probably the outstanding one in the world today. I know of only one power plant where higher temperatures are used, although I may be mistaken on this subject. The Detroit Edison Company has welded an experimental superheated steam plant operating at 1000° F., but the operating pressure at this temperature is around 400 lb. at the most. For the installation described by Mr. Gavit, there are not only extremely high temperatures but there is also the combination of very high pressures. This installation is of such a pioneering nature, requiring such heavy pipe, that it was necessary to secure this pipe from Germany. There is no one prepared for fabrication of pipe of this kind in this country.

Under these unusual conditions of temperature and pressure, I believe, personally, I would have used straps as we do not have as complete information as desirable in regard to strengths and behavior of welds under stress at these high temperatures. From a mathematical analysis, however, I believe it will be found that the straps are decidedly excessive in size but, as Mr. Gavit pointed out, he probably would not use them again. Theoretically, the straps reduce the stresses in the welds in that they increase both the cross sectional area and moment of inertia at the joint, but it is rather feared that under operating conditions when the straps are as large as used in this installation they may increase the stresses. The actual tension stresses on the butt weld will be reduced under pressure but the stresses in the fillet welds joining the straps to the pipe will be increased due to the temperature differential between the inside of the pipe and the outside surface of the straps.

I do not know the exact experimental values, but it is my understanding that with flanges, where used for connections to valves and other equipment, there may be a temperature differential from the inside surface of the pipe, which in this case is about 850° F., of 300° to 400°. In other words, there is a large temperature differential between the inside and outside area of the flange and it is because of this temperature differential that enormous forces are imposed on the flanged joint and I do not believe there is any flange joint that will hold up satisfactorily year in and year out. Engineers and fabricators have gone to extreme expense in trying to utilize flanged joints, resorting to metal to metal contact, as well as the Sargo joint in which strength is relied upon by bolting and sealed through welding. Eventually, under these high stresses resulting from differential temperature, the bolts creep under long-time loading, throwing the stresses on the small seal weld which, of course, breaks the seal and causes leakage. It is because of the inability of the commonly used joints, as Van Stone, to give satisfactory service under these high temperatures that welding is of necessity being resorted to and no doubt will accelerate the adoption of welding to the lower temperature and pressure services.

EDWARD WALKER (State of New Jersey Department of Labor): I would like to ask why all the welding done on the pipe in the shop was by electric arc welding process and when the pipe got into the field all the welding done there was by gas welding process? Why was this?

MR. VOM STEEG: I don't know whether this is a positive answer to the question, but these high pressure welds were no doubt all made with a heavily coated electrode and they can only at the present time be used satisfactorily in a downhand position. A lot of these position welds were made either horizontal or vertical and there is always danger of undercutting one edge with these heavily coated electrodes in these positions. That is probably why gas welding was resorted to for the position welds.

We hope in the near future to have satisfactory electrodes that can be used in those positions. In fact, there is a lot of work being done on them at the present time.

CHAIRMAN CROWE: I think that answers the question. One is a position weld and the other is a weld that rotates. I wonder if Dr. Jacobus could answer that question. Do you have any particular preference as to the use of ferrules or the non-use of ferrules in piping used for pressure work?

DR. D. S. JACOBUS (The Babcock & Wilcox Company): The question of what method will eventually be used for connecting pipes in power plants is very much in the air. There are some who still do not wish to trust welding with the idea that if a single weld in 10,000 should fail it might be in their particular plant in some place that might lead to injury. The fact is, however, that more and more dependence is being put on the use of fusion welding and a number of us believe that eventually station piping will be welded throughout. In the transition period various ways have been suggested for a second line of defense, so to speak, in case a circumferential weld should fail.

You ask about placing ferrules at the circumferential joints. This has been suggested with the idea of assisting in withstanding the weaving action due to cross-strains. There have been a number of ideas on how ferrules or other constructions might be applied for reinforcing the joints and it would be hard to say whether there would be very much gained over the use of an unreinforced weld.

As I have said many of us believe that the time is coming when piping will be connected by welding throughout, especially for high pressures and high temperatures where there is apt to be difficulty with the present form of flanged fittings. Steam is now used at 850° to 900° F. temperature and working pressures have increased to the neighborhood of 1400 lb. per sq. in. Experiments have been made with independently fired superheaters operating at 1100° F. It is difficult to

* Paper published in May issue of JOURNAL OF THE AMERICAN WELDING SOCIETY.

design flanged fittings which will satisfactorily meet all conditions and with the great advance that has been made in the art of fusion welding it would seem that it should come into use for conditions of the sort. Naturally, care should be taken to secure ductile welds and to guard against grain growth in the metal near the welds, and to properly relieve strains caused by the welding.

CHAIRMAN CROWE: It appears, Dr. Jacobus, if we are going up to 1100° F. operating temperature, we might dispense with the annealing on these pressure joints.

DR. JACOBUS: There are different views as to the best way of relieving the stresses. Local stress relief is generally resorted to. Answering your question, where piping is to be used up to 1100° F. operating temperature the strains due to the welding would be relieved at this temperature; safe practice, however, would call for stress relieving before using the piping under pressure.

MR. VOM STEEG: In answer to the question about the restriction of flow in a pipe by the use of chill rings, as they are called, in welding. If we want to get a weld down to the root without the use of a chill ring we either get "icicles" or we get the equivalent to a reinforcing bead. Either one of these offers a certain amount of restriction to flow. There are a number of different types of chill rings on the market at the present time, and one that seems to be meeting with a considerable amount of favor is made of either rolled or pressed stock and tapered down to either side from the center to almost a knife edge. There are projections pressed around the periphery in the center of the ring to properly separate the pipe at the joint and also to assist in lining it up. In some cases this projection goes all the way around the ring, particularly in the heavier sizes. There is just a question whether these chill rings will offer any greater restriction to the flow through the pipe than the "icicles" or reinforcing bead when they are not used.

As we are coming more and more to class 1 boiler code welding where the heavily coated electrodes are used, it is almost impossible to make a weld and get thorough penetration with these electrodes on account of the large pool of molten metal without the use of a chill ring, and the use of the chill ring is becoming more common for that reason.

I think the objections that have been raised to chill rings in the past were that they were too thick and heavy. The tendency at the present time is to make them of comparatively thin material.

There has been advanced another type of chill ring, which also has the raised projection in the center, to be used in connection with pipe that has been flared out at the ends to accommodate the extra stock of the ring, and thereby offering no restriction to flow. This, of course, is going to make the piping more costly on account of this flaring, and the chill rings in this case are drop forged, also adding to the cost of the installation.

This may answer some of the questions raised by Mr. Horgan as to whether a chill ring should or should not be used.

CHAIRMAN CROWE: This last would only lend itself to full length pipe fabrication.

MR. VOM STEEG: These chill rings can be used on either straight runs or in connection with turns of the "Tube Turn" type as they are now making chill rings that are flared out at one end so as to accommodate a turn on its inside radius.

MR. GREENE: The Pressure Piping Code now under formulation by the A. S. A. has incorporated a formula for wall thickness which is the first official recognition differentiating welding from screw joints. This formula is for inspection purposes to determine the minimum wall thickness which, of course, influences design. The thickness t is determined by the usual Barlow formula $\frac{PD}{2S}$, where P is pressure and D is outside diameter. S is the design stress value which varies for different materials. Seamless, of course, has the highest rating with fusion, lap-welded and butt-welded pipe being given a lower value. To the above formula is added a constant "C." The value of "C" will vary for different services but tentatively it is established as 0.05" where the pipe is plain end, welded or Van Stone. For threaded joints the added constant C must be the depth of the thread, which for the ordinary run of pipe is about 0.1 in. The formula, therefore, sets up a differential between plain end pipe and threaded pipe.

Of course, to the classification of welded joints in plain end pipe must be included all types of joints where the metal is not removed when making the joint. I think it is interesting to know there is a timely recognition of the merits of welding in differentiating between welded and threaded pipe, particularly in these days where economy is so essential.

MR. P. W. SWAIN (McGraw-Hill Pub. Co.): I would like to ask Mr. Greene a question. In piping which is to be used for steam at, say, 10 pounds' pressure, you wouldn't put 10 in for d in the formula, but would use some higher value. Use of the actual working pressure in the formula would give very thin pipe. There is a great deal of pipe used for such pressures. What is the actual pressure this pipe is designed for?

MR. GREENE: There must, of course, be a minimum thickness.

DR. JACOBUS: I would like to ask Mr. Greene why he says that the constant in the formula for the pipe thickness should be the depth of the thread for threaded pipe. On a number of occasions the Boiler Code Committee has made it plain that the constant in the formula published in the A. S. M. E. Code was not based on the depth of the thread. It so happened that the constant in the formula of 0.1 inch represented the depth of the thread for the larger sizes of threaded pipe, but the formula was not made up on this basis.

In making up the formula the thickness called for was intended to take care of cross-strains and a certain amount of corrosion, and was considered to be suitable for the use of either Van Stone joints or threaded joints.

The bursting strength of threaded piping is not ordinarily reduced by the threading on account of the reinforcement of the threaded ends by the fittings to which the pipe is connected.

The A. S. M. E. formula allows something for corrosion, but not a definite amount. It has been shown that a threaded pipe is affected more by corrosion at the threaded ends than one with Van Stone joints. There may, therefore, be an advantage in departing from the use of threaded pipe in certain cases.

The thickness of the pipe was considered to be that adapted for resisting the pressure combined with stresses due to cross-bending and to the weight of attached piping, etc. The amount of corrosion that could be allowed for was not specified in bringing out the formula.

MR. GREENE: In regard to the application of the formula for low pressure where the value t would be very small, the minimum thickness is determined by using 100 lb. as the pressure in the formula. In the formula there must be added the factor of C which is added for corrosion, I imagine, among other things. It does not give a full differential between the minimum theoretical thickness for strength of the plain end pipe as compared with metal removed in threading, but only about one-half.

Concerning Crater Formation

By PROF. GILBERT E. DOAN

†Professor Gilbert E. Doan is Associate Professor of Metallurgy, Lehigh University. This paper is a contribution to the work of the Fundamental Research Committee of the American Bureau of Welding.

A FEATURE of the liquid stage which is continuously present during the arc welding operation, and one that is of interest, is the phenomenon of crater formation. Why does a crater or pocket, lined with liquid metal, form beneath the electrode, as shown in Fig. 1? Partly, this crater is due to the pressure of a gas or electron stream that seems to originate at the electrode tip and to flow toward the crater and *blow* the liquid metal outward from the center of the molten puddle toward its edges. Measurements of the pressure of this stream have been made by Donath, in Berlin, and by P. P. Alexander[1] at West Lynn. Similar measurements have been undertaken by other investigators.[2] But the pressure of this "gas stream" is not the only force which acts to form the crater, as the following description will show.

Roentgen,[3,4] in investigating the effect of vapors upon the surface tension of liquids, placed an ordinary-sized funnel, in which lay a sponge soaked in ether, vertically above a smooth, carefully purified water surface, so that the lower end of the funnel tube almost touched the surface of the water (see Fig. 2). The ether vapor, being heavier than air, descended through the tube of the funnel to the water and dissolved in the water surface. This solution of ether vapor in the water surface caused a depression or crater in the water surface whose deepest point was directly under the axis of the funnel tube, where the ether was most concentrated. The ether had lowered the surface tension of the water, and had lowered it most where the concentration of ether was greatest, that is, at the point directly under the middle of the funnel tube. In this water crater concentric circular waves formed continually and moved outward to the edges of the crater, similar to the ripples shown in the solidified welding crater of Fig. 1. If a trace of oil is introduced onto the surface of the water, the following effects are observed: The waves disappear, while the depression or crater remains; instead of the waves, there appears a ring-shaped surface of sharp boundaries, somewhat raised above the level of the crater. The water seems motionless, but in reality is not, for if a light object is thrown into the center of the crater, it will move rapidly outward to the edges of the crater in a centrifugal direction. If the funnel is removed, the crater closes and disappears. The diameter of the ring-shaped surface depends on the amount of oil introduced. The more oil, the smaller the ring. If a large enough quantity of oil is used, the central crater alone remains. The quantities of oil which are necessary to produce the ring-shaped surface and to cause decrease in its diameter are extremely minute. The oil layers thus produced are far too thin to show the interference colors commonly seen in oil films. What has happened is that as soon as the solution of ether below the funnel tube is sufficiently concentrated, the surface tension of the water decreases at that point and the equilibrium of the water surface is upset, resulting in the radial flow of the water away from the point beneath the funnel. This radial flow lays bare a clean water surface. This accounts for the return of the oil film, etc.

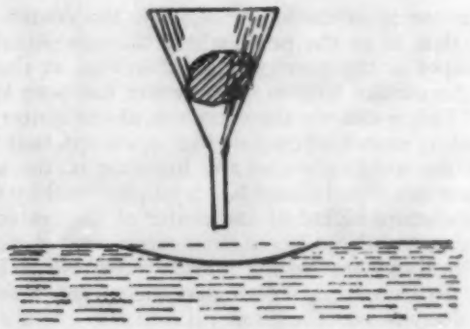


Fig. 2

Another simple demonstration of the effect of vapor upon a water surface may be made in the following way: A cylindrical piece of charcoal is soaked in ether and then covered with paraffin, except for one end of the cylinder which is left uncoated. The ether can vaporize from this open end only. Now, if the piece of charcoal is placed on the surface of the water, it will dart about rapidly for a long time, with the uncoated end of the cylinder to the rear. The surface tension of the water is greater at the front end of the piece of charcoal than it is behind where the ether vapor has lowered the surface tension.

Roentgen's simple experiment with the funnel utilizes conditions quite similar to those in the crater of an electric welding arc, although this may not at first seem obvious. As shown in Fig. 1, the deepest part of Roent-

[1] P. P. Alexander, "The Calorimetric Study of the Arc," *Transactions A.I.E.E.*, 1930.
[2] J. Kelleher, *Transactions American Electrochem Soc.*, XXXVIII, 1920. Duffield, Burnham and Davis, *Proceedings of the Royal Soc.*, **97**, 1920. R. Tanberg, *Physical Review*, **35**, 1930.
[3] W. C. Roentgen, *Wied. Ann.*, **46**, 152 (1892).
[4] G. Bakker, Kapillarität und Oberflöchenspannung, *Handbuch der Experimental Physik*, Leipzig, 1928.

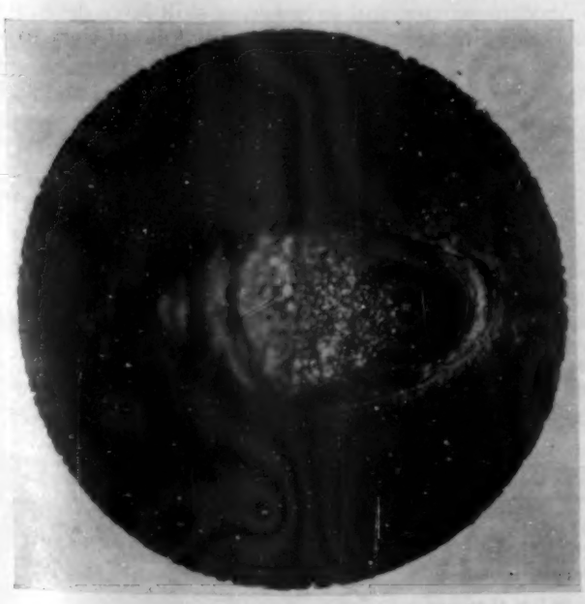


Fig. 1

gen's crater is immediately beneath the center of the funnel, that is, at the point where the concentration of ether vapor is the greatest and, therefore, at the point where the surface tension of the water has been lowered most. This is exactly the condition at the center of the arc welding crater, shown in Fig. 1, except that in the case of the welding crater the lowering of the surface tension of the liquid (iron) has been produced by raising its temperature higher at the center of the crater, than at its edges, while in Roentgen's experiment it was produced by dissolving in the liquid (water) some foreign vapor. Eoetvoes has shown that the surface tension of liquids decreases as the temperature rises. It is zero at the critical temperature. If the center of the welding crater is the hottest region in the crater, and there can be no reasonable doubt that this is the case, then the center of the crater must also be the region of lowest surface tension of the liquid iron, and therefore, as in Roentgen's funnel experiment, the region of greatest depression. Even the concentric circular waves which Roentgen saw are reproduced in the weld crater, shown in Fig. 2, where they have frozen upon reaching the colder edges of the crater. The radial flow of superheated molten iron (low surface tension) away from the center of the crater lays bare the cooler metal of higher surface tension which was beneath it. The depression at the center and the radial flow are, therefore, continuous. The roughness observed at the bottom of the crater in Fig. 1 is no doubt due to escape of dissolved gases during solidification after extinction of the arc.

It is repeated here again that the pressure effect originating at the cathode does account in part for the formation of the welding crater, but that even if this pressure were entirely absent, a crater of this same kind would form as a result of the temperature gradient in the pool of liquid metal. The significance of this interpretation of the welding crater, founded on Roentgen's experiments with a water surface, is obvious.

Abstract of Paper on Oxyacetylene Welding in Production

By **H. O. T. RIDLON**

✦This paper was presented at the March 4th meeting of the Chicago Section of the American Welding Society, by H. O. T. Ridlon of Barrett Hardware Company. The photographs and information in regard to them were supplied by H. A. Goodwin of the Bastian Blessing Company.

THERE are three principal factors in connection with production welding and cutting. They are (1) proper use of equipment, (2) production methods and use of jigs, (3) the operator or the human element.

Proper Equipment

According to figures with which most of you may be familiar, the last census available for 1929 on the consumption of oxygen and acetylene through welding equipment shows that in 1929 there were consumed 3 billion feet of oxygen and nearly 1 billion cubic feet of acetylene.

The manufacturers of acetylene and welding equipment have made very rapid strides in the past few years, in the development of torches. One says or describes a welding torch as merely a couple of valves—tubes—mixing chamber—handle—tip, etc., that's all a welding torch is—simple, isn't it? But, because of the tremendous speed of flame propagation, 330 ft. a second, these simple elements must be combined accurately, scientifically and with master craftsmanship. Your old equipment, whether it is a torch, a regulator or a hose, cannot give you the efficiency you demand for any type of welding any more than a car of 10, 12 or 25 years' vintage can give you the economical, dependable service that you demand.

Modern science and engineering skill have developed torches which are adaptable to every kind of work to be

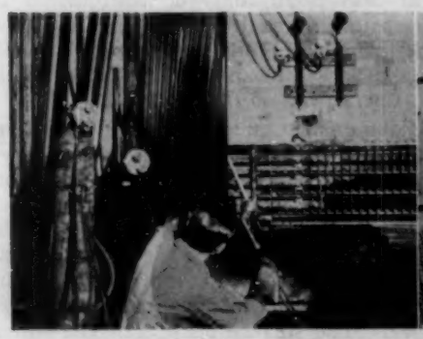


Fig. 1—Production welding of risers to Shelby tubing headers on heat exchanger coils of refrigerating units. These units are for use with sulphur-dioxide, methyl-chloride and ammonia gas and vary in length up to 30 ft. Vertical, overhead and position welding is required. The finished unit is tested to pressures up to as high as 1500 lb. per sq. in. There are anywhere from 10 to 50 welds per unit.

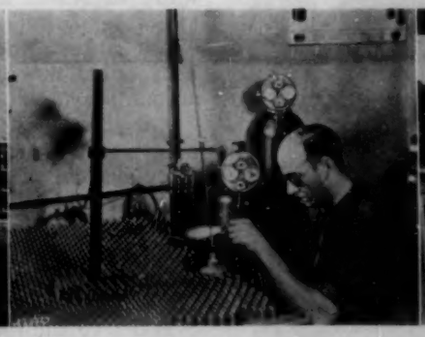


Fig. 2—Production silver-soldering operation in the manufacture of high pressure brass fittings. Unit production—18 seconds. Operator sets up his own work (included in this time). These fittings are for controlling high pressure gases and are tested to 2300 lb. per sq. in. By the use of high speed mass production welding equipment production costs have been lowered and leakage has been reduced to less than one tenth of 1 per cent.

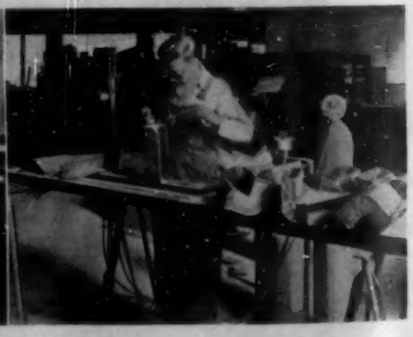


Fig. 3—Production manufacture of ducts for conveying high temperature air in industrial baking equipment. The manufacturer has neglected to employ jigs. The result is slower production rates and greatly increased loss of time for aligning the work preparatory to welding.

Fig. 4—Production welding and brazing fin-coil air conditioning units. Note that the work is very carefully aligned and jigged preparatory to welding. Also that it is placed in a position convenient to the operator, thereby greatly increasing his speed of production and quality of workmanship.

done; you cannot possibly do correctly light aircraft work with some heavy duty outfit any more than you can perform heavy work with an aircraft torch. Also, on production work a heavy, cumbersome torch slows up the operator, tires him unnecessarily with its weight and improper functioning, therefore it is vitally important that in production work the operator be supplied with a torch designed for the job he is doing.

The regulators on an outfit are the heart of the outfit itself—and unless they are modern, up-to-date regulators, kept always in good repair, they can't possibly deliver the constant torch pressure you demand because of the variable tank pressure.

At one time I was working on a production job with three other men, and requested permission of the welding foreman, who happened to be a machinist, to bring into the factory my own light aircraft torch which was particularly adapted to the work we were doing at that time. It happened to be a government job. The other operators were using shop equipment and found difficulty in making $7 a day for 13½ hours' work; I had no difficulty in making $11 and $12 a day with my torch. The government had an inspector on the job and I dare say an estimate of 5% of the work the other men turned out were rejects; I had no rejects in those two weeks, and we turned out 10,000 pieces among the four of us. It is a matter of simple mathematics to figure the economy which would have been derived from the installation of proper equipment.

Jigs and Their Proper Use

The aircraft industry has been the leader, and maintained the lead in the use of jigs; they have given it no end of thought—study—and serious consideration because welding, if properly done, is the correct method of fabricating the steel construction of aircraft; the aircraft industry, though in reality being older than the welding industry, is still in its infancy and many people consider it unsafe—we won't discuss that—but the aircraft industry demands, because of its own hope for development, that its metal parts be fabricated correctly and any improvement it can discover is adopted by it regardless of cost.

In the majority of aircraft factories, they have what is known as the production line—or the bench line—which employs anywhere from a few to many welders. Directly back of this line usually are stationed the bench mechanics, who fit and set up into the jigs the various parts to be used in the construction of aircraft; these are usually termed "fittings." In most aircraft work, there is a right and a left hand fitting to every ship. Result—a right and left jig. As these fittings are put into these jigs, the bench man places them on the operator's table; the operator then tacks them in a designated number of places. This tacker is usually a welder who has possibly not had excessive aircraft experience and is not a master aircraft welder, for aircraft welding is an art in itself. Then the part is removed by the bench mechanic and is passed down the line to the master aircraft welder, who completes the weld.

To tell you how to construct jigs is a rather difficult and possibly foolish thing for me to attempt, because the basic principles are the same with slight variations. The jig should be designed for the work which is to be done—but be sure when you consider making jigs that you consider all angles. The little extra time spent in designing and engineering that jig correctly will more than pay for itself. If you are doing production welding, the most important thing to be taken into consideration is speed and assurance of good welds, providing, of course, you have good operators. The next thing to be considered, or possibly before the jig itself, is to be sure that the operator can work continually in a comfortable position—that he does not have to be cramped—that he has freedom of his muscular control, for he is working always under physical tension.

Operators

In the construction of the fuselage, two master aircraft welders work on each fuselage—one on each side. In the

Fig. 5—Production brazing of the diaphragm plate and drive shaft for a benzine bellows or sylphon-type heat regulating device. These small units are made of steel and are subject to a direct load of 250 pounds. On tensile test the drive shaft itself breaks with no distress to the brazed joint, at a direct load of 1620 pounds or 54,950 pounds per square inch tensile strength. Production rate 300 per hour. This is a case of redesign engineering whereby the manufacturer has eliminated five distinct operations in the manufacture of this unit. In previous mode of assembly it was necessary to notch the drive shaft, perforate the diaphragm, rivet the shaft into the diaphragm, maintain perfect alignment of the riveted parts before brazing and to store lots of as high as 15,000 pieces before operating the brazing furnace. By proper redesign, by utilization of mass production welding equipment, suitable jigs, the manufacturer released valuable floor space, improved the quality of his article, eliminated leakers, mis-aligned parts and made it possible to produce in quantity lots 50 units at as low a unit cost as it was formerly necessary to produce in quantity lots 15,000 units. The helper loads and unloads the jig. The welder, on the left, does nothing but braze the part.

aircraft factories, piece-rate was once adopted, but very soon abandoned, because it was found more advisable to instruct the operators to take all the time necessary to make a weld—but to make it right. These welders are usually very closely watched by a welding foreman and assistant welding foreman, and sometimes one or more inspectors—and it is not hard to tell if a man is soldiering on the job. The welder receives a respectable wage, depending upon his skill. Possibly some of you gentlemen do not believe that an operator in an aircraft factory receives sufficient remuneration—but this is 1932—not 1927 or 1928, or during the War—times have changed. In the smaller aircraft factories, where they employ one or two men as welders, these men, of course, are required to do all the work, but nevertheless the use of jigs still holds forth and is given proper consideration.

One of the most recent production operations that I have had the pleasure to observe, was at a stove factory. It was a brazing operation. The work was fast—the men had the proper ventilation in the room—fans to blow the fumes away from them—and the selection of the rod to be used and the torches was left to the men themselves; the cost of equipment and rod was of very little consideration to the manufacturer. More and more industries are following that system—which is worthy of consideration. Metal furniture builders are going to it. However, very few of them fully realize what it is all about.

In a plant in Cleveland where I have worked a number of times—due to no particular desire on my part to work there, but merely because they usually had a great deal of work and it happened to be a handy stopping off place where I could pick up a few weeks' wages while looking for a better job—was one of the places which had absolutely no conception of the use of jigs, the proper equipment or consideration for the men themselves. The operators, when they needed a tank of gas, had to go and get it and roll it up to their work, which was usually a block or a block and a half from the welding room—which was an outrageous waste of time and money, because they had the proper equipment to deliver the tanks to the welding room. Their work was all piece work and the rates were set by men in the office who knew nothing of welding except it was a fabrication of metal—they had absolutely no knowledge of how long it would take a man to make a weld of a certain kind on a certain job. In one particular operation they contracted to do some work on an estimate that a welder could turn out six an hour—I happened to be the one selected to start this job. I don't claim to be the best or fastest welder in the world, but as a general thing, I have been able to make my rate, but on this particular job on which I was supposed to turn out six an hour, I worked as fast and as hard as I have ever worked, and after three hours I had turned out eight. The result was I had nearly two weeks' pay coming and decided I had had enough of that job for a while because of that experience and because the equipment was obsolete and in very poor repair and totally unsuited to the work to be done.

Pediatric Building for the Boston City Hospital, Shop and Field Welded

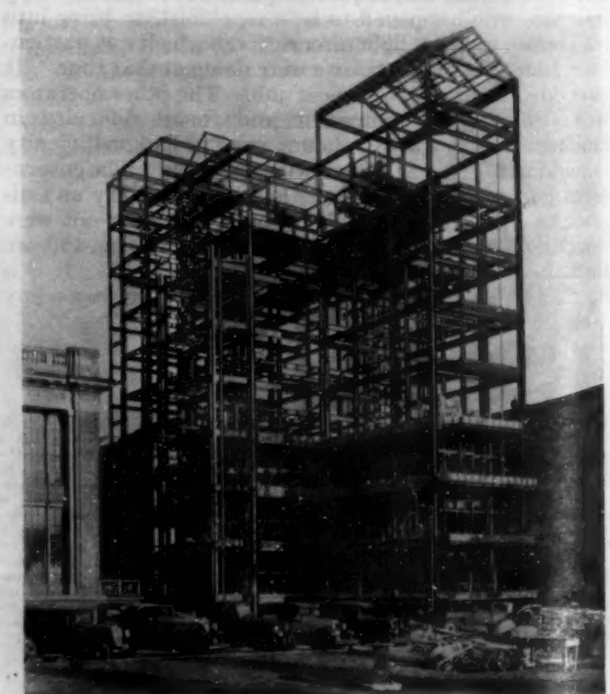
By J. THEODORE WHITNEY

✦Mr. Whitney is President, The Whitney Engineering Co.

FREEDOM from noise was the primary consideration in the erection of the new Pediatric Building for the Boston City Hospital. Originally turned bolts in reamed holes in the field were specified, but the lack of noise and economy due to welding determined the final decision to field weld the structure.

The Boston Building Law has a flexible provision allowing the Building Commissioner to allow the use of materials or methods not covered by the law after satisfactory evidence has been presented. Building Commissioner Roemer of Boston approved the specification, methods and procedure and, as a result, this building became the first municipal building to be welded. It is also the first fire-proof building in Boston to be both shop and field welded.

The Pediatric Building is about 117 ft. to the roof of the 9th story with a pent house and solariums extending higher, making the highest piece of steel to be welded 131 ft. above the ground. In plan the building is 143 ft. long by 43 ft. wide with projections at the center of the two long sides about 12 ft. by 28 feet wide with porches at each floor still farther out, about 9 ft. by 28 ft. wide. It



The Pediatric Building, Boston

is of fire-proof construction, one way combination system being used for floor and roof construction.

Steel erection began October 13, 1931. The erection derrick was taken down November 25, 1931. Welding in the field began October 23, 1931, and was completed December 16, 1931.

All structural steel was fabricated by welding, in the Chicopee Plant of the Palmer Steel Co., Springfield, Mass., and was well ahead of field requirements at all times.

Welding details, made by the welding consultant, covered typical connections, column splices, etc., and many special details due to the fact that architectural requirements made most of the beams come off the center of the columns. The details showed shop and field welding to be done and identical copies were used by the steel company's detailers, the field welding foreman and the field inspector.

Sufficient bolts to allow the structure to be plumbed and aligned were used in the connections, and were left in place after welding. No punching, except in a few special cases, was done in any girder or beam, the holes for the bolts coming in the connection angles. The columns were punched to receive the erection bolts.

For a typical connection to a column face, a right angle was shop welded to the column face as an erection seat. A pair of side connection angles were shop welded to the beam web, with erection holes in the outstanding legs to match erection holes in the column face. The field weld was applied vertically along the toes of the connection angles at the column face. Angles which were welded along a rolled edge were $^1/_8''$ thicker than the nominal size of the fillet required, in order to obtain a full sized fillet along the rolled edge.

For connections into columns between flanges, a seat angle was fitted between the column flanges, with the horizontal leg toward the column web. The vertical leg of the angle was shop welded to the inside faces of the column flanges, these welds carrying the load. For rigidity during erection, a clip angle, shop welded to one side of the beam web, was provided with two bolt holes in the outstanding leg to match holes in the column web. The field welding of this connection was at each edge of the bottom flange of the beam to the seat angle for a length of about 2". The top of the beam was stayed by field welding a light plate connecting the top flange of the beam with the column web.

For some of the intermediate flush top beams a projecting plate, shop welded to the top flange of the intermediate beam, over the cope, rested on the top flange of the girder and supported the beam in position. One end of the beam was cut, sawed or milled. At this end the web of the beam was placed in contact with the girder web and field welded directly web to web. These welds were placed as close as possible to the neutral axis of the beam, in order to keep the secondary stresses as small as possible. The clearance was thereby thrown to the opposite end of the beam where loose plates about $2^1/_2''$ wide, one on each side of the beam web, were field welded to the beam web and to the girder web. This type of connection was used only where no beam framed in directly opposite on the other side of the girder.

The building was designed to resist wind pressure in the narrow positions. The side clip connections carry the dead and live load shear, the top and bottom connections being provided to resist wind moment only. Many of the wind connections were eccentric with the columns, in some cases the web of the girder being off the column face entirely. The amount of welding necessary on account of eccentricity was naturally more than would have been required had the connections not been eccentric.

For a typical column splice for columns of the same nominal size, but where the column depths varied by $^5/_8''$, a $^3/_8''$ filler plate was shop welded on each face at the upper length of column. These fillers were slightly larger than the splice plate, in order that the splice plates could be welded to them. Two erection bolt holes were provided in each splice plate and corresponding holes in the lower length of column. After the column was plumbed, the lower half of the splice plates were field welded to the lower length of column. The lengths and sizes of welds were designed to resist the stresses due to the wind bending moment, only the direct load being taken by bearing through the milled ends of the columns. For column splices where the filler plates required were less than $^3/_8''$, rather than use long and small fillets between the fillers and columns, the fillers were spot welded to the splice plates and were made the same width as the splice plates. A triangular fillet was built up to the full thickness of filler and splice plate, though the strength of this fillet was considered as only a $^3/_8''$ or $^1/_2''$ fillet, corresponding to a $^3/_8''$ or $^1/_2''$ splice plate. The splice plates were field welded to the lower column length as before.

For splices where the nominal size of column changed, a cap plate was shop welded to the lower length, with two erection bolt holes in the plate, matching holes in the outstanding legs of clip angles field welded to the web of the upper column length. The moment was resisted by horizontal welds at the outside of the column flange to the cap plate.

Welding both for shop and field was carefully designed to be accessible for the welder, and overhead welding was practically eliminated.

Shop welding was handled by a welding foreman and a total of seven welders was qualified for work in the shop. These men did not spend all their time on this job as other welded jobs were being put through the shop at the same time. The welding foreman was accepted as shop inspector with periodic supplementary inspection by the welding consultant personally or by the writer.

The field welding was done by two welders and a welding foreman, part of whose duties was supervision.

The field welding inspection was done through the office of J. T. Whitney, Boston, Mass., Welding Consultant. A qualified welder was employed as field inspector, whose duty it was to check lay-outs as made by the welding foreman, check the completed work for quality and agreement with the plans, and to further check the quality of the work by having the welders make lap welds from time to time which were broken and examined for quality. Occasionally light connections were purposely broken off, and the quality of the welds examined. The inspector also made daily reports of the number of inches of weld by size and location, with the name of the welder making each weld. The writer also made daily visits to the job particularly to check for miscellaneous items which might appear on the job and which were not apparent during design. The welding consultant also visited the work from time to time to check general procedure.

All welders, both in the shop and in the field, were tested by visual and laboratory tests before being permitted to weld on production. To be acceptable, the applicants were required to satisfy the requirements for tests practically the same as those recommended by the AMERICAN WELDING SOCIETY'S Code for Fusion Welding.

The following table gives pertinent data on this work:

Field Welding

Total steel	492 T
Total fillets, all sizes	25686 in.
Total equivalent $^3/_8$ fillet	29365 in.
Fillet, all sizes, made with gasoline driven machine	177 in.
Fillet, all sizes, made with motor driven machine	25509 in.
Equivalent $^3/_8$ fillet made with gasoline driven machine	229 in.
Equivalent $^3/_8$ fillet made with motor driven machine	29136 in.
Total welding hours	557
Fillet, all sizes, per welding hour	46.1 in.
Equivalent $^3/_8$" fillet per welding hour	52.7 in.
Fillet, all sizes, per ton of steel	52.2 in.
Equivalent $^3/_8$" fillet per ton of steel	59.7 in.
Electrode used and wasted	1120 lb.
Electrode melted (assume 80%)	896 lb.
Electrode melted by motor driven machine	890 lb.
Current used (by motor driven machine)	4150 kw. hr.
Current consumed by Foreman's machine when idling, 134 hrs. at 1.25 kw.	170 kw. hr.
Current used in welding	3980 kw. hr.
Fillet (all sizes) per kw. hr.	6.4 in.
Equivalent $^3/_8$ fillet per kw. hr.	7.3 in.
Electrode melted by 1 kw. hr.	0.22 lb.
Fillet (all sizes) per lb. of electrode used and wasted	22.9 in.
Equivalent $^3/_8$ fillet per lb. of electrode used and wasted	26.2 in.
Fillet (all sizes) per man day of 8 hrs.	30.7 ft.
Equivalent $^3/_8$" fillet per man day of 8 hrs.	35.1 ft.

Shop Welding

Total steel	492 T
Total fillets (all sizes)	37138 in.
Equivalent $^3/_8$" fillet	45627 in.
Fillet (all sizes) per ton of steel	75.5 in.
Equivalent $^3/_8$" fillet, per ton of steel	92.7 in.

The architectural and engineering design was done by James H. Ritchie and Associates, Boston. The steel was furnished and fabricated, including shop welding, by the Palmer Steel Co., Springfield, Mass., and was erected by Daniel Marr and Son Co., Boston. The field welding was done by Mellon, Taylor, Hendrickson, Inc., Philadelphia, Pa. Mr. J. T. Whitney, President of The Whitney Engineering Co., Boston, Mass., was welding consultant in charge of welding details, qualification of welders and inspection, and was assisted by A. S. Coombs, Engineer, The Whitney Engineering Co. Professor Frank P. McKibben, Black Gap, Pa., was associated with Mr. Whitney in an advisory capacity.

A New Process for Making Welded Joints

By H. S. GEORGE

†This paper was presented at the Annual Meeting of the American Welding Society, April 27 to 29, 1932, by H. S. George, Research Engineer, Union Carbide and Carbon Research Laboratories, Inc.

Introduction

THERE have been, until recently, only two fundamentally different methods of making welded joints in metals. The origin of these two basic methods is lost in antiquity. Both require the application of a considerable amount of heat. One employs force to effect a union, the parts being in a solid but plastic condition, while the other method unites the objects by melting the contiguous parts.

Before the advent of modern high temperature agencies, steel could be welded only by the first process, that is, forge welding. Metals of relatively low melting point, lead for example, have long been welded by the second method, known as fusion welding. But as the mechanical arts advanced and as new sources of energy became available, steel and other high melting point metals have also come to be welded by the fusion process. At the present time there are many modifications and combinations of the two older basic methods. The modern methods differ chiefly in the source of energy and in the form of apparatus employed.

Recently, a new method of welding steel has been developed and placed in commercial use. Like the two other methods, it requires the application of considerable heat, but the parts do not need to be raised to the melting temperature of the base metal, nor do they need to be forced together. A welded union is effected by heating the parts to about the same temperature that is employed in forge welding and then uniting them with molten filler or weld metal, as is now done in fusion welding. The molten weld metal unites and becomes integral with the adjacent solid parts by utilizing a number of peculiarly cooperating properties of carbon and iron. Therefore the method does not fall under either of the older classifications, but forms a distinct third class. It is unique in being the only method of making a welded joint (considered fundamentally) of whose origin there is any exact knowledge.

Definitions

The older methods of soldering, brazing and welding will be analyzed, briefly, to form a basis for discussing the new process. Such operations are characterized by many common features, and some writers classify them all under the name of welding. The matter is largely one of definition and, because there is none that is generally accepted, it may be well to state what these terms mean in the present discussion. The term "weld" may indeed be used generically, to include all joints, soldered, brazed or welded, that have the common characteristic of having been united, in metal-to-metal contact, by means of heat. But it is possible to weld without heat and, moreover, if "weld" is used generically, there is no suitable name left to distinguish the result of a forge or fusion weld from a soldered or brazed joint. The difference between such joints is one with which the present article is concerned, and the term "weld" will therefore be retained to designate the products of the forge and fusion processes and also that of the new process. This leaves the need for a generic name for all such joints, but with that need the present article is not concerned.

Joints that are soldered or brazed have in common a sharp line of demarcation with little or no mingling or interdiffusion of the filler metal with the base metal parts. "Base" is here used to signify the parts that are to be joined, and is distinguished from the "filler" metal which acts as a cement in a soldered or brazed joint. Filler metal may be used in fusion welding (and in the present process), and there are instances of its use in forge welding. But in the last three, all

classed herein as welding, the filler metal is not used merely as a cement and there is no sharp physical line of demarcation between the weld metal and base metal, the two mingling or diffusing.

One way to appreciate the difference between the two classes of joints is to consider that in the one (soldering and brazing) it is possible to separate the parts completely, for example, by melting out the filler metal, thus restoring the original surfaces, whereas in the other, (welding) the original parts can never be restored even though a substantially lower melting point filler metal may have been used to unite them. This indissoluble characteristic is adopted in the present article to distinguish a welded joint.

Essential Requirements

In any operation of this sort (soldering, brazing or welding), there are three essential requirements (to be discussed in more detail later), the principal one being to eliminate the oxide which forms on heated metal and which otherwise would prevent intimate metal-to-metal contact. Soldering and brazing rely on a suitable flux for this purpose, which unites chemically with the metallic oxide and disengages it from the metal surface. A drop of molten solder and a piece of copper will not cohere because the thin films of oxide on the copper and on the solder prevent them from uniting molecularly (that is, metal-to-metal). The shape of the drop of solder where it rests on the copper is convex; the solder does not "wet" the copper. But if a flux is applied the solder assumes a concave meniscus. This is because on removing the oxide film the molecular attraction of the two metals overcomes the surface tension of the liquid solder and pulls it along the surface of the copper; in other words, the solder now "wets" the copper. The same is true of brazing.

In the case of a forge weld, force is used to squeeze out the oxide and to bring the surfaces into contact. The objects are usually prepared with convex surfaces to facilitate the squeezing-out process. A flux is usually relied upon to reduce oxidation and to unite with and render the metallic oxide fluid. Slag, or fluxed oxide (although sometimes hardly distinguishable), always remains as a discontinuous film at the boundary of a forge weld, but except where the slag film is present a true weld (indissoluble union) occurs.

Fusion welding may also employ a flux, but usually, in the fusion welding of steel, the removal of the metallic oxide is accomplished by melting the oxide coated parts, which permits the lighter oxide to float to the surface

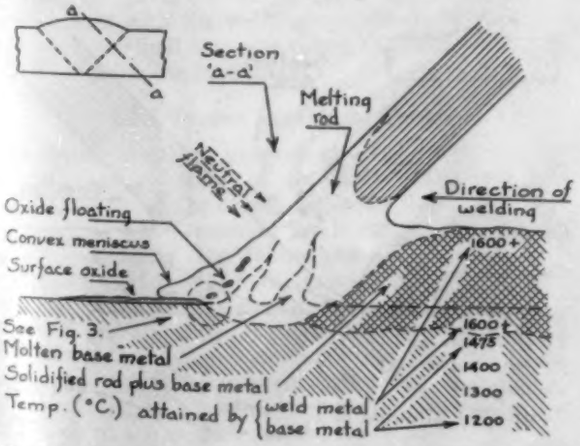


Fig. 1—Fusion Welding, Showing How the Surface Oxide Is Floated Off to Obtain Contact, by Melting the Base Metal

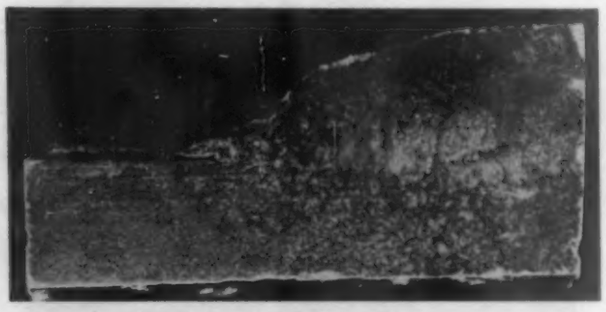


Fig. 2—×3. Photomicrograph of Fusion Weld. Section taken at the forward edge of the advancing puddle. This corresponds to the sketch, Fig. 1. Observe the weld metal overlapping the surface oxide; observe the deep fusion and the depth to which the heat effect has affected the base metal.

of the puddle. The molten rod metal, if any, mixed, of course, with such base metal as has been melted to effect removal of the oxide, then makes contact with the base metal and unites with it. Figure 1 depicts the operation, diagrammatically, and Fig. 2 is a corresponding photomicrograph of a fusion weld. Figure 3 is a photomicrograph of the same weld, taken at a point corresponding to the dotted circle in Fig. 1, showing the oxide melting and rising to the surface of the puddle.

In each of the above methods, three essential requirements must be fulfilled: (1) removal of oxide; (2) contact between the parts; (3) sufficient heat to facilitate the operation and render it commercially feasible. In the new method, certain distinct but cooperating functions of carbon are utilized in connection with each of the above three essentials.

Relationship of Carbon to the Essentials of Welding

It is worth while to note the contrast between the slow empirical development through the centuries of the simpler alloys of iron and carbon and the greatly increased tempo in this respect resulting from the application of modern research methods. This does not mean that the elements of chance and necessity are no longer of account in discovery and invention, but these factors are relegated more and more to the occasion of the particular discovery, while scientific knowledge and modern facilities play an increasing part in assisting the inventive faculties in seizing the occasion and in meeting the necessity. The remarkable combinations of iron and carbon to form the steels and cast iron have long been used without, until recently, much of an understanding of the intricacies of the relationship. The new welding process is in reality an extension of this unique partnership scientifically discovered and applied.

When carbon dissolves in solid iron, which it does rather rapidly at elevated temperatures, the melting point of the mixture falls below that of pure iron. The more carbon, up to about $4^1/_2$ per cent, the lower the melting point, pure iron melting at about 1530 deg. C., while the $4^1/_2$ per cent, or eutectic mixture, melts at about 1150 deg. C. If, therefore, we heat steel containing, say, 0.35 per cent carbon, whose melting point is about 1500 deg. C., to a temperature somewhat below this, say, to 1200 deg. C., and then expose it to a carburizing influence, the surface layer of the white-hot steel will absorb carbon and will spontaneously melt as soon as the carbon content approaches $4^1/_2$ per cent. The molten carburized film covering the surface of the steel precludes oxidation.

If molten steel is allowed to run over the surface of white-hot steel thus carburized, the molten surface film

Fig. 3—×100. Photomicrograph of Fusion Weld Showing the Area Indicated by the Dotted Circle in Fig. 1. Observe the surface oxide that has started to float up through the weld metal. It is this melting of the base metal—to float off the surface oxide and to bring about contact between weld metal and base metal—that distinguishes fusion welding from forge welding and the new process.

is immediately dissolved in the molten steel, which thereupon unites with the underlying solid metal. Figure 6 shows how the above occurrences are integrated with welding, using an oxyacetylene flame to unite two continguous plates by filling the intervening space between their beveled edges with metal melted from a welding rod, which is caused to unite with the plates through the medium of the carbonaceous flux, as described above.

It is very difficult to retain the carbonaceous film for microscopic examination, because it is so thin. By exaggerating its formation it can be retained, and such an example is shown in Fig. 5 which reveals the iron-carbon alloy of approximately eutectic composition (4 to 4½ per cent carbon).

The forward edge of the advancing puddle of weld metal as it progresses along the seam, having absorbed the carbonaceous flux, contains about 0.40 per cent carbon, whereas the finished weld has less than 0.30 per cent carbon, being diluted with rod metal. The finished structure of a fully annealed weld is shown in the photomicrograph, Fig. 6.

The welding operations and properties of the weld will be discussed more fully later, the above brief references having been introduced to provide a basis for the discussion of the functions of carbon which now continues.

The carbonaceous film performs three functions, each related to the three essentials enumerated above, which are required in any welding operation, viz.: (1) it prevents oxidation; (2) it promotes intimate contact by acting as a flux and by causing the molten metal to run out over the wetted base metal; (3) it acts as a temperature indicator, denoting by its formation and spontaneous melting the proper time to add the molten filler metal.

Table I shows how the essential requirements are obtained in the various welding processes and similar operations.

The underlying principle or basis of the new process is comprised of a fortunate and peculiar coincidence of a series of cooperating facts, namely: *carbon is soluble in iron; carbon lowers the melting point of the mixture; the melting point of the carbon mixture coincides with a feasible welding temperature; carbon reduces iron oxide; the non-metallic product of the reduction is gaseous, and escapes.*

Another fortunate consideration from the standpoint of commercial feasibility is that the necessary carbon is available and controllable with standard oxyacetylene welding apparatus, and the present article, while concerned with the broad principle, deals chiefly with this natural development.

The Utility of Carbon in Oxyacetylene Welding

Although the standard oxyacetylene welding apparatus is all that is necessary, the method lends itself to semi-automatic and automatic operation, and special apparatus has been developed for certain applications of the new process, taking advantage of its essential simplicity.

In practice, the carburization of the base metal, as a preparation for receiving rod metal, is accomplished by the oxyacetylene flame properly adjusted and manipulated. A flame having a slight excess of acetylene is the one generally used because it facilitates the operation without unduly carburizing the weld. For certain special types of work, carburization of the base metal may be obtained by proper manipulation of a flame which is essentially neutral in adjustment as a free-burning flame.

The blowpipe is manipulated in such a manner that the carburizing zone covers the base metal adjacent to the advancing weld. As the weld progresses, the adjacent base metal absorbs carbon to a depth of about one or two thousandths of an inch, forming a high carbon film that spontaneously melts as soon as its temperature reaches 1150 to 1200 deg. C., as already described. The natural shape of the flame and the disposition of its zones make this a very simple and practically automatic procedure.

There is no fixed requirement as to whether the base metal shall or shall not be heated to its melting point or even higher, after carburizing.

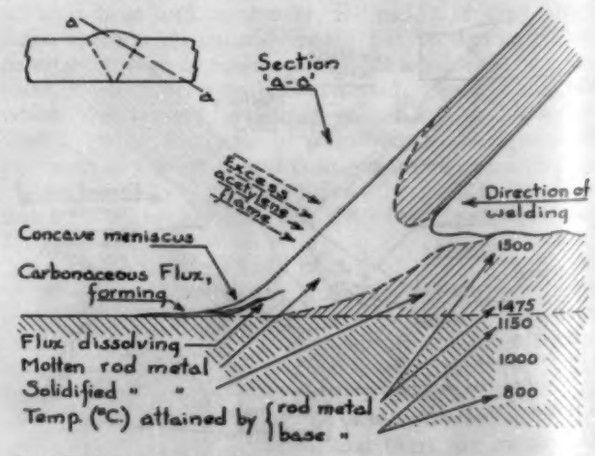


Fig. 4—Self-Fluxing Process, Showing How the Carbonaceous Fl... Obviates Melting the Base Metal

Fig. 5—×100. Photomicrograph of Carbonaceous Flux, Exaggerated for Purpose of Study. As produced in the normal welding operation, it is so thin that its retention for examination is practically impossible. This exaggerated example was specially made to show its eutectic structure, how it eliminates oxide and how it forms on the unmelted base metal. In the actual welding process carbon does not diffuse so deeply into the base metal as is shown above.

The Carbonaceous Flux

The one indispensable characteristic of the method is the formation of the carbonaceous film as a flux to enable the filler metal to unite with the base metal.

This film possesses certain unique features. It is metallic; it is produced automatically; it spontaneously melts; and it disappears by dissolving in the added metal as soon as its functions have been fulfilled. The process may therefore be technically termed "self-fluxing." It is the basis of the method now known to the welding industry as "Lindewelding."

The idea of utilizing the carbonaceous flux in welding occurred to the author during the course of an examination of a number of experimental welds made by a combination of the forge and fusion processes. Under the microscope, thin films of oxide were observed, marking the boundaries of the original surfaces. Previous studies made by the author on special purpose fluxes suggested the idea of trying a carbonaceous flux. The problem then resolved itself into devising some means of integrating and synchronizing the formation of the carbonaceous flux with the welding operation. The thought occurred that possibly the oxyacetylene flame itself could be made to provide the necessary fluxing carbon. To test this conjecture the following steps were taken. The beveled edges of a joint were pre-carburized superficially with an oxyacetylene flame for some distance along the seam, and weld metal was then added in the usual manner. The results confirmed the theory. Next, the carburization was combined and synchronized with the welding operation. This proving successful, the final step was taken, the weld being made without melting the base metal.

The Excess Acetylene Taboo

As the development progressed it became increasingly evident that in spite of the long-established taboo against the use of the excess acetylene flame, here was a method that was capable of producing welds of superior quality. Actually, the taboo had applied only to the welding of mild steel, for the excess acetylene flame has been used for certain purposes, such as the welding of special alloys, and a heavy excess is often used in welding steel where the occasion demands a hard weld. Moreover, some welders customarily employ a barely perceptible "feather" of excess acetylene to act as a visible indication of the desired neutral adjustment.

In the art of coating steel with certain non-ferrous alloys, Haynes Stellite for example, a heavy excess of acetylene is essential to insure sound coatings by preventing access of atmospheric oxygen. In some such cases the carbonaceous flux was incidentally formed, but its utility had not been recognized in making welded joints in mild steel or ferrous alloys, and all texts and authorities have been explicit in warning against the use of anything but the so-called neutral flame for the oxyacetylene welding of mild steel. It is believed that at the time of the present discovery there was no published record of any application of the principle of the carbonaceous flux either in coating or making welded joints, nor of any instance (other than forge welding) of welding mild steel without raising the contiguous parts of the joint to the melting temperature of steel.

The present method operates at a lower temperature than fusion welding, and superheating of the rod metal to float out oxides is unnecessary. Moreover, in order to obtain satisfactory results, it is essential to use a rod of special composition to provide addition agents, as in steel founding, of which welding is a specialized miniature replica.

One of the former objections to the excess acetylene flame was its supposed deficiency in heating ability and consequent bad effect upon the speed and economy of welding. It will be shown later how the reverse effect was actually demonstrated.

Properties of the Weld

Where a rod containing, say, 0.15 per cent carbon is used with the new method to weld plate having a carbon content of between 0.15 and 0.35 per cent, the weld metal will contain about 0.25 to 0.30 per cent, or approximately the same amount as the base metal. A lower carbon content can be obtained if desired. The physical properties of such weld metal are superior on the whole to those of the plate. Ductility is retained at a high value because of the soundness and oxide-free character of the deposited metal. In the "as welded" state, welds of the type mentioned above as made in the laboratory have outpulled plate having a tensile strength of over 90,000 lb. per sq. in. At the same time ductility of these welds, as measured by the bend test, ranged from 20 to 25 per cent. The normalized welds had a ductility of between 40 and 50 per cent, while that of fully annealed welds was even higher. When it is considered

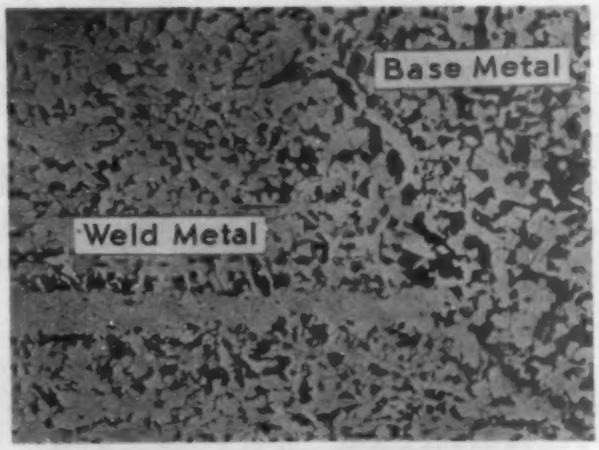


Fig. 6—×100. Showing the Annealed Structure of the Weld at the Junction with the Base Metal. The carbon content is accurately indicated by the structure. The ghost line and parallel slag inclusions, extending in unchanged form close to the junction, indicate the relatively low temperature to which the base metal was heated, about 1100 to 1200 deg. C.

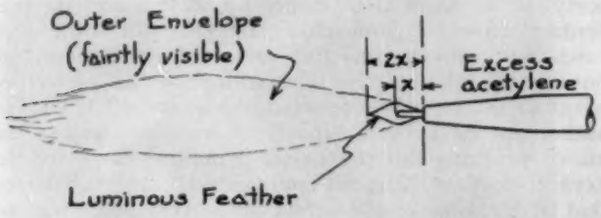


Fig. 7—Flame Adjustment Generally Used with Self-fluxing Process

that a ductility of 15 per cent is ample, denoting sound weld metal and toughness, the high quality of the weld becomes apparent. Given good ductility and high strength, the need is not for the sacrifice of strength in order to obtain more ductility, but for soundness and absence of defects, such as incomplete penetration, especially at the root of the vee. The presence of the carbonaceous flux covering the walls of the vee is virtually a guarantee against such defects.

A noteworthy feature of the new type of weld is its improved response to heat treatment. An important example of this is exhibited by chrome-molybdenum aircraft steel. Butt type joints in tubular test specimens 1 in. O. D. by 0.035 in. wall thickness were welded without melting the tube, using the same rod mentioned above; then heat-treated after welding, some to 125,000 and some to 150,000 lb. per sq. in. In all cases the full heat-treated strength was realized. The fractures occurred 3 to 4 in. from the weld, proving that there was no deleterious effect from the welding operation. Thin chrome-molybdenum plate, also, was heat-treated after welding to various strengths, from 125,000 to over 200,000 lb. per sq. in. Upon testing to failure, the heat-treated strength was attained, the fracture occurring in the plate, remote from the weld, with the weld reinforced only 30 per cent. With the reinforcement ground off, and with reduced sections at the weld, similar specimens broke in the weld at 80 per cent of the strength of the alloy steel, the fracture being silky and of the cup and cone type indicating homogeneous, tough weld metal.

Preparation

There is a precaution to be noted in connection with the self-fluxing method to insure a sound weld, in addition to the exercise of reasonable care to avoid unduly superheating the rod metal above its melting point. It is essential that the base metal be properly prepared to receive the carbonaceous flux. The best preparation is either a smooth machined surface or a smooth blowpipe-cut surface, preferably made with a machine-operated blowpipe. Very rough or deeply rusted surfaces or those with heavy mill scale or having very sharp wire edges should be avoided as they are likely to cause

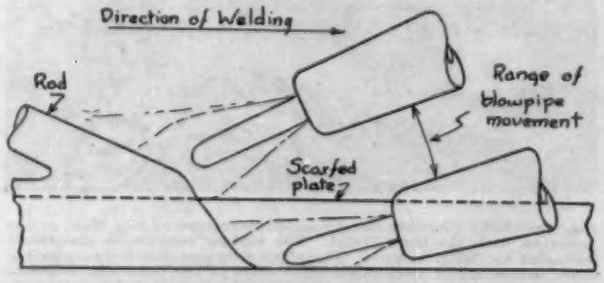


Fig. 8—Lindewelding by Backward Method. Side view of longitudinal section through single vee weld in plate

blowholes, the reason being that the quantity of carbonaceous flux usually formed is not sufficient to reduce completely the oxide on such surfaces before the advancing puddle encloses them. The incomplete reaction $FeO + C = Fe + CO$, proceeding within the puddle, forms a blowhole due to the generation of carbon monoxide. Thin mill-scale, ordinary rust and the oxide on blowpipe-cut surfaces are reduced completely by the flux and are not objectionable. In actual practice, if a heavy particle of oxide is met with, its presence is unmistakably indicated by its extremely brilliant appearance long before the puddle engulfs it. It may then be melted and floated out as in fusion welding.

Flame Adjustment

When hand welding by the self-fluxing method, the excess acetylene flame is usually employed. The flame adjustment generally recommended is one having a "luminous feather" about two times the length of the inner cone (see Fig. 7). When the excess acetylene flame is manipulated according to the usual technique, one criterion for controlling the proper adjustment of the gas mixture is the character of the sparks which are emitted by the pool of weld metal. If too much acetylene is supplied or if the blowpipe is not manipulated properly, characteristic scintillating sparks are emitted in a steady shower. These are similar to the "carbon sparks" produced when high-carbon tool steel is held against an emery wheel. On the other hand, when too little acetylene is applied, "oxide sparks" become too frequent. With the correct mixture and manipulation an occasional spark of either variety may appear but never a steady "shower."

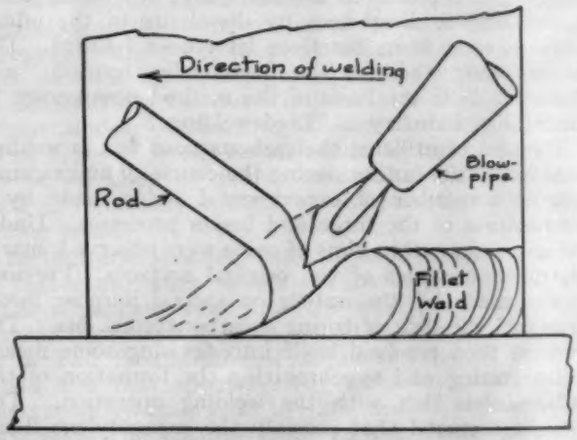


Fig. 9—Lindewelding by Forward Method. Side view of fillet weld

For most purposes, especially where the contiguous parts are beveled, the backward method (see Fig. 8) is preferred. In some cases the forward method (see Fig. 9) is used, especially for thin gage metal, but even for unbeleved sheet metal the backward method is sometimes indicated. Where this is the case a flame, whose adjustment as a free-burning flame may vary from a barely visible feather of excess acetylene to neutral, usually suffices to produce an ample carburizing effect when manipulated in the proper manner.

Contrast in Procedure of Oxyacetylene Fusion Welding and the New Process

The early experimental work in connection with the self-fluxing process was aimed at the development of a

Table 1—Essential Requirements

Method	Elimination of Oxide	Metal-to-Metal Contact	Adequate Temperature	
			Base Metal	Filler Metal
Soldering and Brazing	Flux	Fluidity of Filler Metal	Melting Temp. of Filler	Melting Temp.
Forge Welding	Force	Force	1100–1300° C.	.....
Fusion Welding	Melting of Base Metal (and Filler Metal, if any)	Fluidity of Base Metal (and Filler Metal, if any)	1600° C. (+)[1]	1600° C. (+)[1]
Self-Fluxing Process	Carbonaceous Flux	Carbonaceous Flux on Base Metal and Fluidity of Filler Metal	1200° C.[2]	1475–1500° C.[2]

[1] At least 100 deg. superheat required, to float out oxides.
[2] Correct temperature indicated by melting of carbonaceous flux.
[3] No superheat required.

suitable technique for procedure for the welding of butt joints in mild steel plate. As in welding butt joints by the oxyacetylene fusion process, the contiguous edges require beveling. In general, the oxyacetylene fusion process employs a technique known as "forward" welding, with the edges beveled at an angle of 45 deg. This results in a vee-shaped trough having an included angle of 90 deg. The large angle is considered necessary to insure thorough "fusion" and "penetration." As used by the welder these terms mean the intimate mixing of the molten rod metal with the molten base metal over the entire beveled surfaces, accomplished by progressively melting the opposing beveled surfaces over a limited area and filling the intervening trough-shaped space with metal melted from a welding rod whose end is suitably manipulated in the advancing puddle of steel. As the forward edge of the puddle continues to advance along the open vee, its rear edge solidifies. A suitable manipulation of the blowpipe is required which, in combination with that of the rod, enables the welder to control the puddle and to float out oxides.

The self-fluxing process presents a strong contrast to the foregoing. For butt type welds, the "backward" method is employed (see Fig. 8). This method had already shown certain advantages over the forward method, and its technique lent itself to the self-fluxing principle but it had not been widely used, in this country at least. The operator now merely directs the suitably adjusted flame so as to form the low-melting carbonaceous film continuously just ahead of the advancing puddle, and, because oxidation is eliminated and the base metal remains solid, there is no necessity for complex movements of the rod or the blowpipe.

Correlative modifications in welding procedure follow naturally. The most important of these from the standpoint of economy is the increase in the size of the welding flame that can be safely applied.

Another marked economy that appeared early in the development work was the considerable reduction in the included angle of the vee over that which was generally considered necessary in fusion welding. Instead of 90 deg., a 70 deg. angle is sufficient. This difference represents a saving in welding rod of from 25 to 50 per cent, depending upon the thickness of the material, the spacing and the amount of reinforcement.

Inherent Advantages

There now follows a more detailed discussion of a number of advantages inherent in the new method.

From the standpoint of economy, it is of decided advantage to be able to weld without heating the base metal to its melting point or above. Not only does it require a smaller energy input to prepare the base metal but its preparation requires less time.

It is well known that in general the less a metal is superheated above its melting point, and the less a weld is worked over, the better is its quality. With the new method the weld metal need be heated only sufficiently to cause it to conform to the scarfed surfaces. A barely molten condition of the weld metal suffices, and due to the more rapid rate of welding and the smaller amount of heat absorbed by the base metal, the puddle solidifies more quickly. Bathed in a reducing atmosphere, the metal is continuously protected from oxidation.

It is remarkable that the many correlated effects of the self-fluxing principle should all be cooperative in promoting both quality and economy. One of the most interesting of such examples is the relative heating rates of the neutral and the excess acetylene flames. Heretofore, it has been considered that the neutral flame produced the highest temperature and consequently was the most efficient adjustment for welding and the one yielding the greatest speed. But the author has shown that a flame, adjusted so that the luminous feather has a length of about $2x$ (see Fig. 7), will melt a welding rod faster than the natural flame, for the same size of blowpipe tip. The increase in melting rate is quite appreciable, amounting to from 5 to 10 per cent, where both flames are directed at the rod in the same way, and where the working distances and positions correspond to those in practice, the tip orifices and oxygen pressures being equal.

There are several possible causes for the faster melting rate of the excess acetylene flame. In the first place, the proper flame adjustment is preferably obtained not by cutting down on the oxygen supply, but by increasing the acetylene supply. Thus more energy is supplied because about half the primary energy is in any case derived from the exothermic decomposition of acetylene. Again, part of the enhanced heating power is probably directly due to the "luminous feather." The effect of this more voluminous and luminous flame is twofold. It provides an insulating medium surrounding the rod, and its luminosity increases the radiant power of the flame. Finally, although the temperature immediately in front of the inner cone is theoretically (and, no doubt, in fact) higher in the case of the neutral than of the excess acetylene flame, the probability is here suggested that the mean temperature throughout the working range of the flame is higher for the latter because of the differences in the rates and processes of combustion in the two cases.

Several results of the new welding principle cooperate in promoting quality. For example, the ability to produce a weld without melting the base metal prevents the dilution of the rod metal with base metal of inferior quality. This means that, with the aid of a special welding rod having a composition designed specifically for welding purposes, the quality of the weld is actually superior to that of the base metal.

Laboratory Research Proved Practical

The attainment of these results in the laboratory research has been amply confirmed in actual practice, notably in the construction of overland pipe lines for transporting oil and gas. Every conceivable service condition has been imposed on the procedure and on the lines welded by it, during a period of more than a year and on over three thousand miles of pipe. The simplicity of the method has been evidenced by the readiness with which the laboratory-developed technique is assimilated by the novice as well as by experienced welders.

The method lends itself to machine welding and semi-automatic welding, because its principle obviates complex movements of the rod and blowpipe.

A striking example of the superiority of the new process from the standpoint of quality has recently been referred to in Air Commerce Bulletin 16, issued by the United States Department of Commerce, Aeronautics Branch, giving advance information on some of the results of the Bureau of Standards' recent investigation of the strengths of welded joints in tubular members for aircraft. One of the problems in the program was the welding of joints in very thin chrome-molybdenum tubing, having a wall thickness of only 0.020 in., and successful welds were made with ease with this new process.

Summing up, it may be said without exaggeration that the self-fluxing method has revolutionized welding practice where it has been applied, by greatly increasing welding speeds, by effecting economies in consumption of rod and gases, and at the same time maintaining uniformly excellent quality.

In conclusion, the author wishes to acknowledge the cooperation and assistance of others—particularly of Mr. P. C. Jones, who made the welds in the adaptation of the process to the technique of backward welding—and he desires to emphasize the importance of modern research facilities in this connection, as exemplified by the activities of Mr. J. H. Critchett, Vice-President, Mr. J. R. Dawson, Head of the Welding Department, and other members of Union Carbide and Carbon Research Laboratories, Inc.

Written Discussion of Mr. Jennings' Paper on Ductility

By J. C. Lincoln*

✦Mr. Lincoln is Chairman of the Board of the Lincoln Electric Co.

IN MR. JENNINGS' recent paper he has a number of figures indicating that the ductility of a test sample as reported increases as the length of the sample decreases.

If my memory is correct he had one sample which had 82% elongation in $^1/_2$". The same material was reported with an elongation of 25% in 2".

I am sending this discussion to point out that in making a pull test there are two factors governing the results in so far as per cent of elongation is concerned. One is the ductility of the metal. The other is the uniformity of the sample being tested.

Fundamentally, ductility is the property of a metal which enables the grains to slide over each other or which enables the grains to elongate in the direction of the force acting without breaking.

Using this definition of ductility, it is clear why a short sample will show a greater percentage of elongation than a longer sample of the same material. As the sample is stretched in the testing machine there will be some particular portion of it which is slightly weaker than the rest and consequently greater elongation will occur at this particular point than at other points. This greater extension decreases the cross section which still further concentrates the strain at this point.

When the break finally occurs the actual stretching of the metal over a $^1/_4$" including the break would probably be more than 100%, although the elongation, as measured over a distance of 2", in the report would be of the order of, say, 25%. The difference in elongation is not due to the fact that the actual ductility in the 2" sample is less than the actual ductility in the particular $^1/_4$" length where the break occurs but is due to the fact that the metal in most of the length included in the 2" is not stretched to anywhere near the degree that the metal is stretched over the $^1/_4$" where the break actually occurs.

To put it another way, in measuring the elongation over a 2" gage length we are measuring not only the ductility of the sample but its lack of uniformity. If the sample were absolutely uniform, every portion of the length in the 2" gage length would stretch an equal amount. Due to the fact, however, that the sample is not absolutely uniform this stretch occurs mostly at the point at which the break occurs. This is the reason why the per cent of elongation in 2" is greater than the per cent of elongation on the same metal as reported with an 8" sample.

The ductility of the metal would be the same in the 8" sample as the 2" or $^1/_4$" sample but most of the metal in the 8" sample is not very severely strained and consequently the reported elongation is much lower in the 8" sample than in the 2" sample.

What we are measuring in all these cases is not only the ductility in the metal but lack of uniformity in the samples being tested. Ductility is a good quality—uniformity is a good quality, but in making pull tests these two qualities should be distinguished from each other.

It would seem to me that the best test for actual ductility would be to take a weld bar, drill a number of holes through the weld so that the break will occur in the weld and not in the parent metal, and measure the elongation of the holes after the break has occurred.

In this way the lack of uniformity of the sample is reduced to the lowest term and what we are measuring is mostly the ductility of the sample, not so much the lack of uniformity of the sample.

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* Paper published in April issue of JOURNAL OF THE AMERICAN WELDING SOCIETY.

Author's Closure Paper on "Ductility in Arc Welds with Some Reference to Strength Values" by C. H. Jennings

It has been the purpose of the writer in his paper on "Ductility in Arc Welds" to discuss the various methods of determining weld ductility and to interpret the same.

The advantages of determining weld ductility by the elongation of tensile specimens lies in the fact that it gives results that are consistent and directly comparable to those obtained from parent metals. The fact that the gage length has an important effect upon the results obtained from this type of test is not an objection to it. Standard methods and procedures have been established for the measurement of ductility in parent metals and a similar procedure can be adopted for measuring ductility in welds.

The advantages of the bend test for ductility determination lie primarily in its simplicity and cheapness. The results obtained are consistent and are directly comparable within themselves, but they appear to have no relation to elongation values obtained from tensile specimens.

The principal factor to bear in mind in connection with elongation measurements (tensile or bend), however, is that they are only an arbitrary measure of ductility and unless they are carried out in standard conventional methods they become misleading.

Worthwhile Saving Effected by Arc Welding Gas Pressure Regulators

By **A. F. DAVIS**

+Mr. Davis is Vice President of The Lincoln Electric Company.

A VERY considerable reduction in construction and assembly costs of a gas pressure regulator unit has been made possible by the utilization of the shielded arc process of arc welding which has made such rapid strides recently.

The unit in question is installed in the Muncie, Indiana, station of the Ohio Fuel Gas Company to reduce the pressure on trunk lines for city use. It consists of six high pressure regulators and 12 gate valves; in the meter end there are seven merco stops and seven gate valves as well as seven 10 in. al-welded orifice flanges. On the whole installation, shown in the accompanying illustration, are 120 all-welded steel flanges. It weighs over 40,000 lb.

Fig. 1—Gas Pressure Regulator Unit

Adaptability of the shielded arc technique is shown by the variety of pipe sizes. The regulator consists of 45 ft. of 16 in. pipe, 22 ft. of 12 in. pipe, 159 ft. of 10 in. pipe, 40 ft. of 8 in. pipe, 80 ft. of 6 in. pipe, 71 ft. of 3 in. pipe, 20 ft. of $2^1/_2$ in. pipe.

The Ohio Fuel Gas Company is an extensive user of welding and is equipped with standardized arc-welded jigs and fixtures for production of fittings. Flanges are cut by gas on an arc-welded automatic set-up and held in position on a special fixture.

STRUCTURAL STEEL REPORT

The American Welding Society has available in attractive book form, the results of a five-year program of investigations in Structural Steel Welding. The report shows allowable unit stresses which may be used for various types of joints and thicknesses of materials commonly met in structural work. Several thousand specimens were made up in forty different shops and tested in twenty-eight laboratories to secure the above results. Price per copy, $1.00.

Pressure Welding of Low-Carbon Steels with Theoretical Considerations on the Mechanism of Such Welding

By C. R. AUSTIN *and* W. S. JEFFRIES

✦This paper was presented before the Annual Meeting of the American Institute of Mining and Metallurgical Engineers, New York, February 1932. The first part dealing with Physical Tests was published in the June issue of the Journal of the American Welding Society.

PART II

Macroscopic and Microscopic Examination

IN ORDER to study the nature of the junction formed between two specimens in pressure welding, macroscopic and microscopic examination was found to be valuable. The macroscopic examination refers to the fracture when this occurred in the weld. The microscope was used to examine the nature of surfaces found in such a fracture and also to observe the metallographic characteristics of polished sections cut longitudinally through the center of the weld. Macroscopic analysis naturally refers only to tests where fracture occurred in the weld. A good weld which broke outside the surface of contact provided no information other than that the experimental conditions were such as to produce a weld stronger than the parent metal.

It was found that much fundamental information was to be obtained from the study of fractures under good binoculars where a stereoscopic view of details could be noted. An effort has been made to reproduce a few of these structures, without the stereoscopic effect, to assist in discussing the problem. It must be borne in mind that they are given to show differences in the type of structure over the surface of any one fracture, but they do not in any way indicate the minute details that can be observed in the stereoscopic examination.

Figures 7 to 10, inclusive, show the different types of fracture that were obtained by breaking welded test pieces. The description of these fractures is grouped into two kinds—a coarse crystalline fracture exhibiting shining crystal facets is referred to as a "fiery fracture" and a fine, gray, dull fracture is termed a "gray" fracture. Accompanying this gray fracture are silver-bright areas which are quite distinct and different in nature from the fiery fracture. It is suggested that this is not a true fracture but will be referred to as the "silvery" fracture.

In Fig. 7 the black and white irregular areas are the places where a fiery fracture has resulted. Symmetrically arranged gray rings show the gray fracture and in between these rings can be observed white ring spacings which we have termed the silvery fracture. This macrograph is the only good photographic reproduction, as the surface of the fracture approximates to a plane surface and the lens used takes care of the slight amount of depth of focus required. The other fractures are so irregular that only a small area on any one setting can approximate to the depth of focus of which the lens is capable.

Thus in Figs. 8 to 10 efforts have been made to obtain a general focus on the gray and silvery structures. For this reason the fiery fracture in each case is unavoidably misrepresented as the black areas in the photograph. Hence, in Fig. 8 can be noticed a gray crystalline constituent, the gray fracture and light speckled areas consisting of a mixture of gray and silver. It is considered that these silvery spots are areas where welding has not taken place. The gray crystalline constituent in this specimen also contains many silvery areas but they are minute and fairly uniformly dispersed.

Figure 9 also shows all these characteristics but rather differently disposed. On the periphery of the sample many bright patches can be observed. These are part of the fiery fracture where crystal facets happen to catch the light; they are not part of the silvery constituent. The latter structure, however, is found in patches in the top right quadrant of the photograph but most of it is again fairly intimately dispersed among the gray material.

Fig. 7—Test 135. Typical Macrophotograph of the Fracture through a Weld Made in Air, Where Only Partial Welding Has Occurred. × 8

Fig. 8—Test 132. Another Type of Fracture Showing Partial Welding. × 8. Dark areas represent fiery fracture; gray and light areas are composite—part weld and part lack of weld.

Fig. 9—Test 291. Macrophotograph of Fracture through Weld Made in Air and Pulled in Tensile Test. ×14. This illustrates three distinct kinds of fracture. Discussed in text.

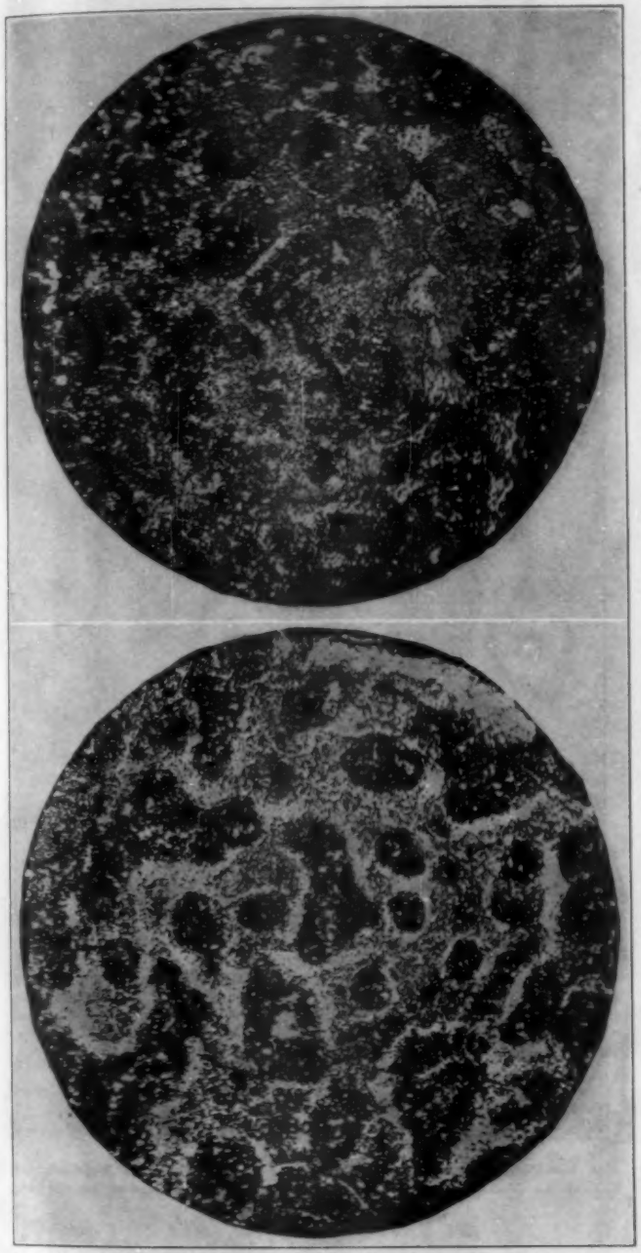


Fig. 10—Test 294. Macrophotograph of Fracture of Tensile Test That Broke in the Weld. Black areas represent fiery fracture; white areas, silvery constituent; gray areas, gray fracture.

Figure 10 differs only in amount and manner of distribution of the three types of fracture. The black areas are again the fiery fractured surface and are distributed in small areas all over the section. The white areas show imperfectly how the silvery constituent is arranged in streamlines around the crystalline patches; the similar form of the gray material may also be noted.

Figure 11 shows the typical appearance of one-half of a tensile test bar which broke in the weld but gave a tensile value of the same order as that of the material, with a considerable elongation (test 275, Table 6). The strength of the weld is good and the weld is also ductile. The reason the break actually occurred in the junction is suggested in the last section of the paper.

Figure 12 shows the fractured induction furnace hydrogen weld. The cylinders were regular, as welded, but efforts to break in the tensile machine were unsuccessful, owing to slipping in the grips, which resulted in distortion of the specimen. Figures 13 and 14 are different positions of focusing vertically down on the fracture of one-half of the test piece. Figure 13 illustrates the complete fiery or crystalline nature of the fracture, and Fig. 14 gives the macroscopic details where welding did not take place, owing to lack of contact. These areas show hydrogen-etched grains. The two half-moons in the center correspond to disregistry of the holes in the cylinders; the upper one is part of the hole in the half photographed, the lower one is not the wall of that hole but part of the plane contact surface which registered with the hole in the upper specimen.

The complete nature of the weld is clearly shown where intimate contact was effected between the two surfaces. The experiment was carried out in hydrogen at about 1400° C., the only pressure used being that due to the weight of one cylinder resting on the other.

Figure 15 shows more clearly, at a higher magnification, the effect of hydrogen etching where good contact does not obtain. This photomicrograph was taken from one of such areas shown in the previous figure. Figure 16 illustrates a somewhat similar result noticed in the silvery areas found in air-welded specimens which subsequently have been fractured and broken in the weld. The grain boundaries are well defined, owing to preferential oxidation or oxide erosion. A similar phenomenon is depicted in Figs. 17 and 18, taken on the rough fractured surface. The former shows, at high magnification, the appearance of the surface of the metal where a bright silvery "fracture" is found and is taken from the fracture reproduced in Fig. 8. The latter is from an air weld. The bright blobs around the oxygen-eroded grains are patches of light reflected along the microscope tube by

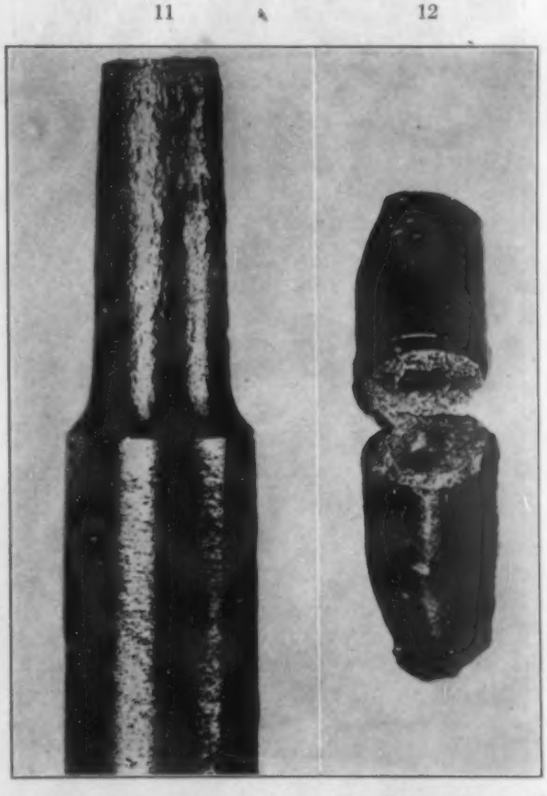


Fig. 11—Test 275. Typical Appearance of Tensile Test Bar that Broke in Weld but Gave Good Ultimate Strength and Considerable Elongation. × 2½

Fig. 12—Specimens of ½ -in. Diameter Fractured after Welding in Hydrogen without Pressure

certain facets of the crystalline part of the fracture, but, of course, are obviously out of focus.

The rest of the figures are photomicrographs illustrating the various types and conditions of structure found in welds of different kinds. They are largely self-explanatory and only short reference will be made to them. The first six photomicrographs (Figs. 19 to 24) show the unetched and etched longitudinal section through a poor, an indifferent and a good weld. The experimental conditions are given in Table 6. All are the same low-carbon, open-hearth steel welded in air at 1425° C. at a pressure of 500 lb. per sq. in. In test 134 (Figs. 19 and 20) much of this pressure was dissipated by the bending of the bars and hence much of the oxide has remained in situ between the contact surface. In test 77 all the oxide film that can be revealed by microscopic examination has been squeezed out and the weld apparently is perfect. Figure 22 shows no indication of the location of the weld and the etched section (Fig. 23) shows perfect continuity of crystal structure.

The fracture of this test specimen, however, demonstrated that complete welding had not been effected. A fiery fracture predominated but the gray and silvery fractures were also in evidence.

Fig. 13—Macrosection of One-half the Fracture Shown in Fig. 12, Focused to Bring Out Clearly Fiery Fracture. ×6

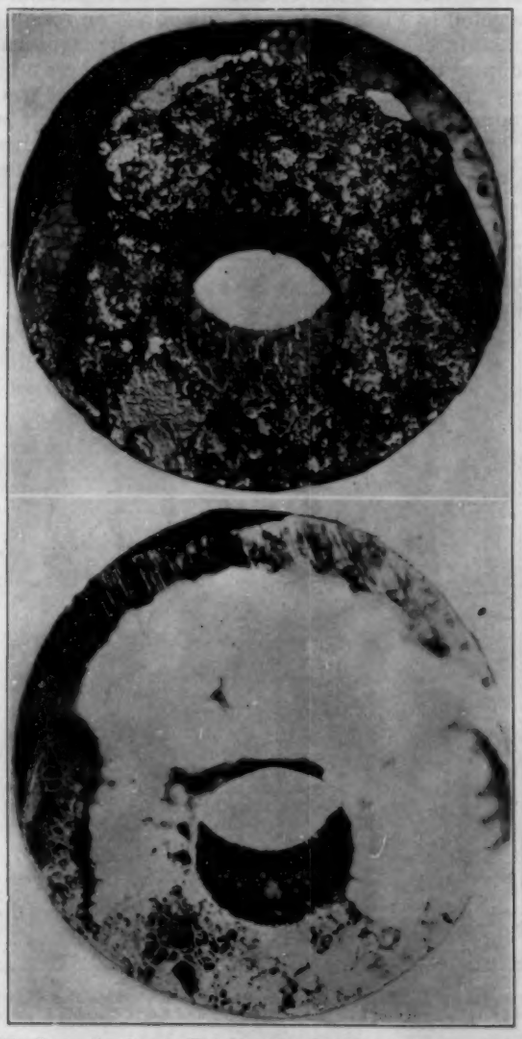


Fig. 14—Same Section as Fig. 13, with Focusing Taken on Area That Failed to Weld. ×6. Hydrogen etching is noticeable where surfaces failed to make contact.

Fig. 15—Photomicrograph Taken from Hydrogen-Etched Area of Fig. 14. ×100. White lines in grain boundaries are due to reflected light from bottom of eroded channels.

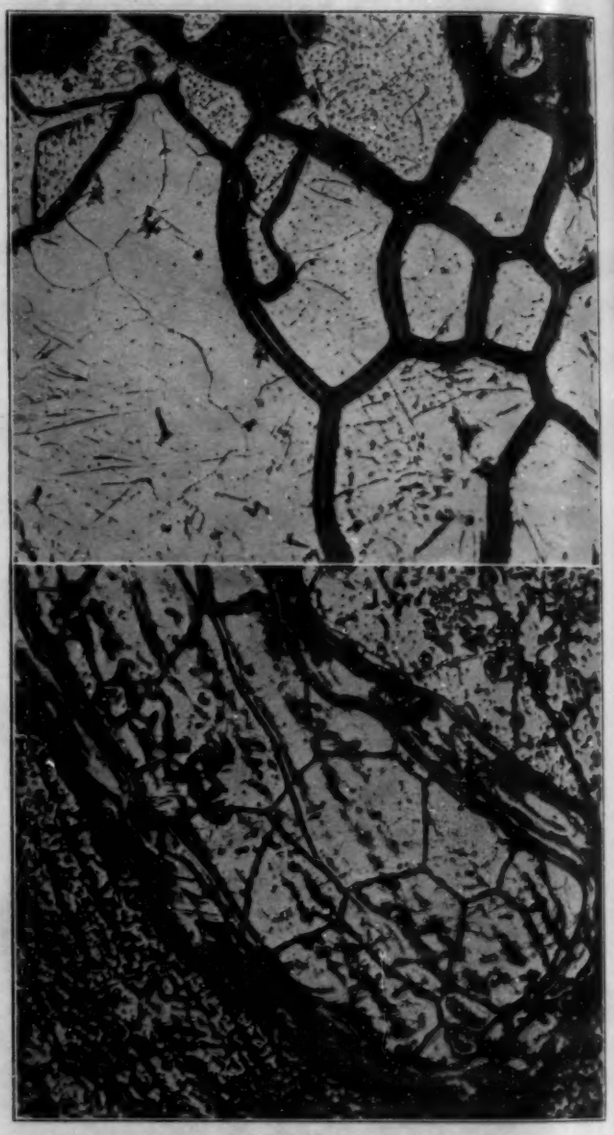
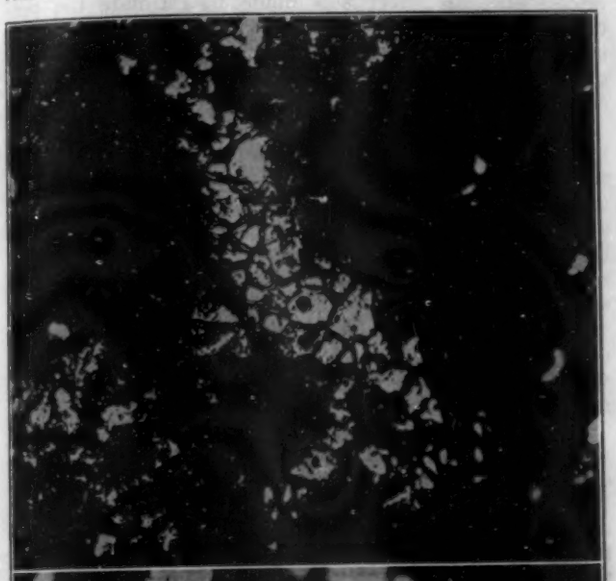


Fig. 16—Photomicrograph of Fractured Air Weld Where Welding Had Failed to Take Place. ×500. Illustrates oxygen erosion or etching around grain boundaries.

Figures 25 and 26 show the microstructure of a very good weld which was made in air at 1400° C. from Bessemer steel. This broke outside the weld at a load of 68,900 lb. per sq. in. and with an elongation of 30 per cent on one inch. Intimate contact of the ends was facilitated by rotating one specimen relative to the other. The only indication of the position of the weld is given by the oxide stringer seen in Fig. 25. Figures 27 and 28 are photomicrographs of a hydrogen weld but a slight oxidation of the junction is noticed in the unetched section. Subsequent fracture showed a good weld.

In Figures 29 and 30 are seen an etched and unetched microsection from a weld which was done at 1400° C. in air to which natural gas was added to decrease the amount and rate of oxidation of the steel. The thin oxide film still persists between the welded ends and what may be termed a preferred grain-boundary orientation on either side of the weld is noticed.

Fig. 17—Test 291. Bright Area from Fracture Illustrated in Fig. 9. ×100. Shows oxygen etching of bright particles observed in that figure.



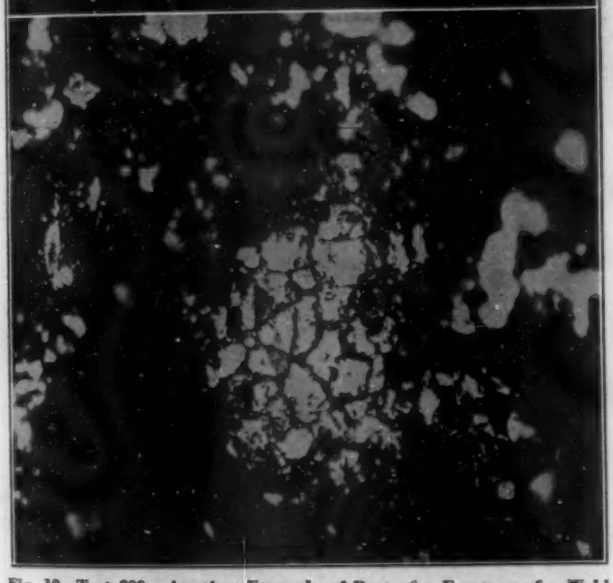


Fig. 18—Test 290. Another Example of Part of a Fracture of a Weld Made in Air, Showing Oxygen Erosion on Bright Unwelded Area. ×100.

Consideration and Theoretical Discussion of Results

The experimental evidence presented above will now be reviewed and consideration given to the mechanism of pressure welding. An attempt will be made to account for the behavior of such welds under various mechanical tests, and for the metallographic features observed under the microscope.

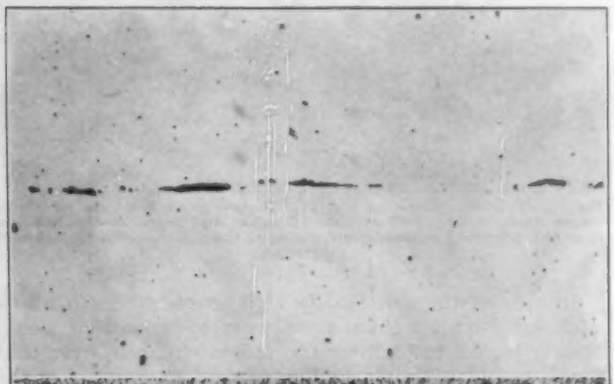
The experimental work consisted essentially of determining the effect of atmosphere, temperature and pressure on pressure welding, using different tests to evaluate the results. In Tables 1 to 5 is collected all the relevant information.

Early experiments refer only to welding in air and these are first discussed. Such experiments revealed that any variation in temperature and pressure in our tests never resulted in the formation of a weld of a strength comparable to that of the parent metal. Only a limited number of these are recorded (Table 4). Such welds, however, gave a fracture which was part fiery where welding had evidently taken place, and part where welding had apparently failed to have been effected and where the fracture passed through the contact surface, giving a mixed appearance of bright and gray particles. Such a condition is illustrated in Fig. 7, and the nature of the latter surface was not understood. Welds of this kind gave what appeared to be abnormally high tensile values. Thus test 115, Table 4, had an ultimate of 37,700 lb., or more than one-half the true tensile of the steel, and yet only about 10 to 15 per cent of crystalline fracture showed in the broken test piece. The remaining 75 per cent was clearly not properly welded and the machine marks on the ends of the rods were still visible (Fig. 7).

A careful consideration of many such experiments, more particularly by observation of the fractures under the binocular or stereoscopic microscope, leads to the conclusion that a distinction must be made between two different types of true welded fracture, and that a classification may be made as follows:

1. An area where welding manifestly had taken place which gave a typical metallic though fiery fracture. This was definite and clearly marked.
2. An area where complete welding had not taken place and where frequently the initial machine marks were still visible on the surface of the steel. This may conveniently be referred to as a "sticking" together of the surfaces.

Fig. 19—Test 134. Longitudinal Section through a Poor Weld. Unetched. × 100. Shows strings of oxide inclusions which have remained in weld.



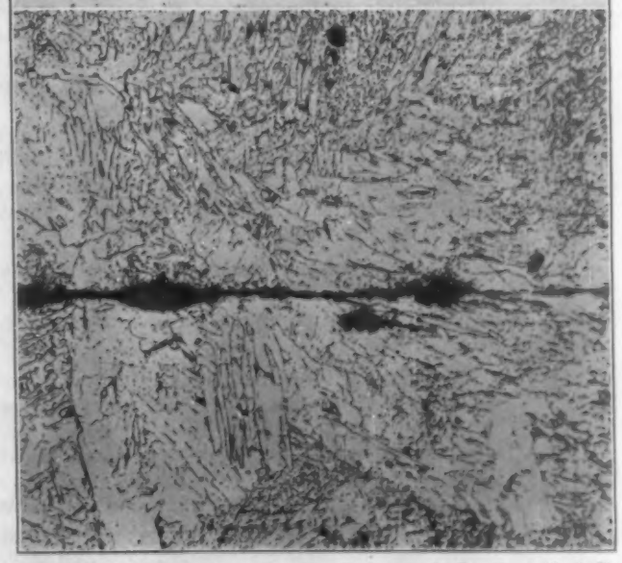
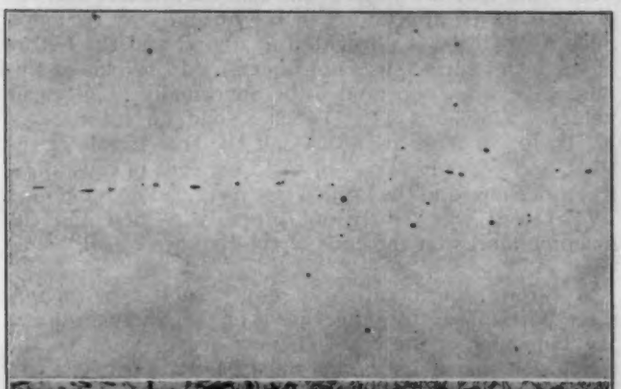


Fig. 20—Test 134. Same as Fig. 19. Etched in 10 Per Cent Alcoholic Nitric Acid. × 100. Illustrates almost continuous character of oxide film remaining in weld junction.

Fig. 21—Test 98. Longitudinal Section through Weld Showing Discontinuity of Oxide Film in Weld Junction. Unetched. × 100.



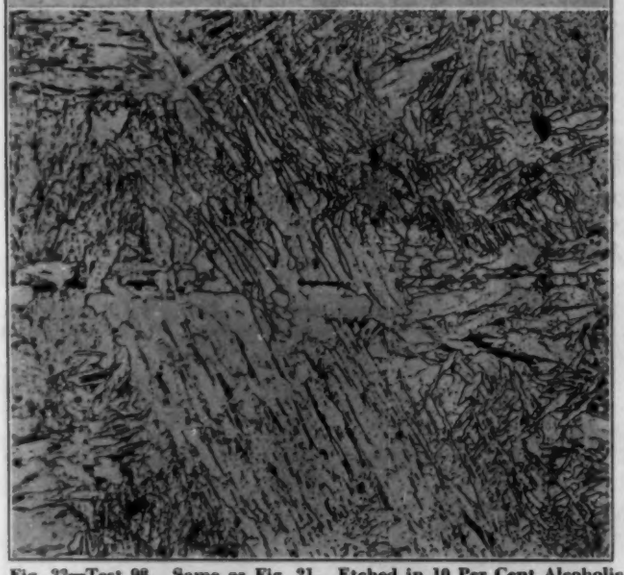


Fig. 22—Test 98. Same as Fig. 21. Etched in 10 Per Cent Alcoholic Nitric Acid. ×100. This reveals a thicker and more continuous film than the unetched microsection, owing to the removal of surface flowed material.

In view of the abnormally high tensile strength which such small truly welded areas seem to provide, it would appear logical to look for the excess strength, over that which would be given by the area of true weld, in the region where "sticking" was evident. This matter was attacked from many different angles and our final conclusions as to the nature of this "sticking" are summarized below.

Without exception pressure welds made in air always broke at least partly in the junction line of the weld and this line always revealed the "sticking" type of fracture, if such it may be called. Again, such a fracture was always composite and included:

1. Parts of this which appeared to be a true gray fracture.
2. Parts which showed complete absence of welding. These unwelded areas include:
   (*a*) A blackened or dark surface having the appearance of iron oxide which had not been squeezed out by the welding pressure.
   (*b*) A bright metallic surface which had failed to weld for some reason, although the experimental conditions apparently were such as to remove all liquid oxide during the time allowed for welding to take place. It is with this bright metallic surface that we are most concerned.

In a survey of these fractures under the binocular microscope, an effort was made to estimate the percentage area of gray fracture. This was done by first noting the amount of crystalline fracture and the amount of bright metallic or silvery area and by difference obtaining the percentage of gray material.

The fiery fracture was easy to distinguish and the estimation is a fair approximation. The bright metallic surface was different. When arranged in stream lines (Fig. 10) this also was simple, but when finely dispersed among the gray (Fig. 9) it was exceedingly difficult and the estimation is probably low in most cases. This means that the percentage of gray and, hence, also percentage of total area welded is, in general, on the high side. However, this figure for the the total weld, as defined by the amount of true fracture (fiery and gray), was correlated with the percentage strength of the steel given by the weld.

It was soon found that the strength of the weld was in nearly all cases considerably higher than could be accounted for by the area of welded section. This strength, however, was not accompanied by a commensurate amount of ductility, nor had many of the welds much resistance to failure by shock. It was necessary, therefore, to look further for some other cause to which the high tensile values and low resistance to shock were due. Such a medium may be found in the postulation of the

Fig. 23—Test 77. Longitudinal Section through Apparently Perfect Weld. Unetched. ×100. No oxide film is noticed, nor can exact location of weld be determined.

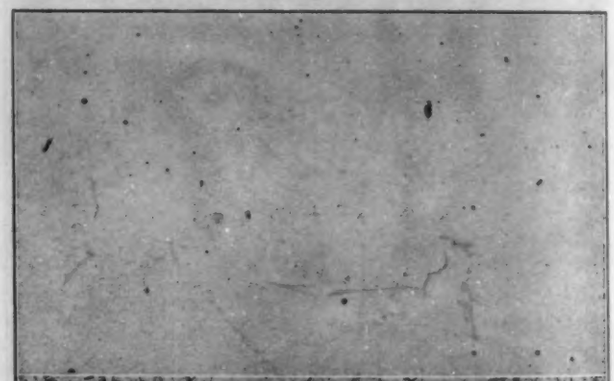


Fig. 24—Test 77. Same as Fig. 23. Etched in 10 Per Cent Alcoholic Nitric Acid. ×100. Etching shows structure in weld but does not reveal its exact location.

Fig. 25—Test 280. Longitudinal Section through Center of Weld. Unetched. × 100. Location of weld is indicated by oxide stringer. Tensile test specimen broke away from weld.

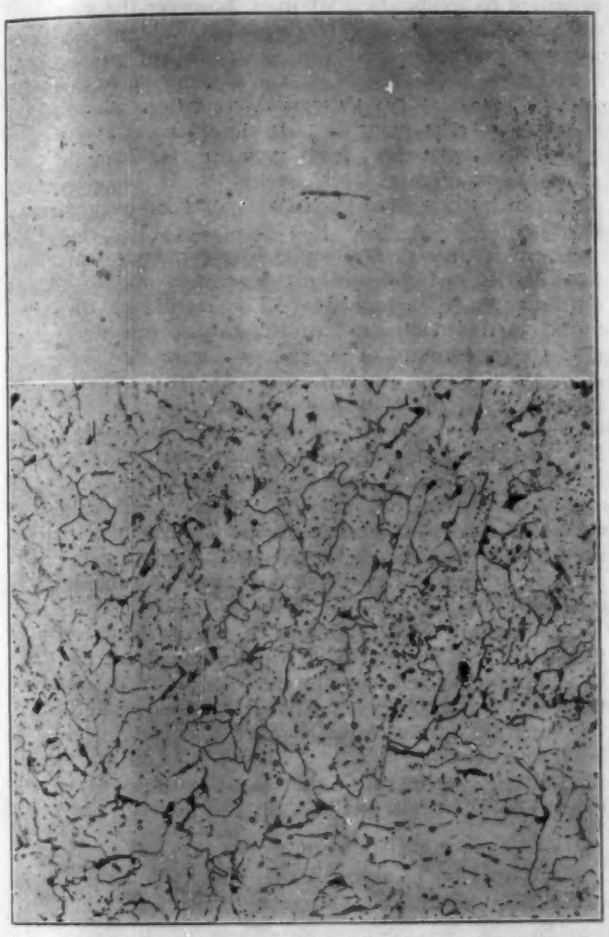


Fig. 26—Test 280. Section Shown in Fig. 25. Etched in 10 Per Cent Alcoholic Nitric Acid. ×100. Oxide stringer has disappeared during repolishing.

presence of a thin nonmetallic film between the metallic surfaces and there is much evidence to substantiate this hypothesis.

When two bars are squeezed together end on, as in our welding test, the liquid oxide is gradually squeezed out, but even at the highest pressures a thin film of oxide remains, separating parts of the metallic surfaces. This film is in no sense continuous and causes contributing to its disruption include irregularities on the welding surface and the introduction of any translatory movement of one surface relative to another. It is well known that thin films are capable of carrying very high tensile stresses and on account of their thinness they transmit little or no shearing stresses. On the other hand, impact or sudden transverse stresses produce failure regardless of the thinness of the film if the film material is anything but ductile.

Thus it is suggested that, over a part of the area in contact, a thin film of oxide prevents joining of the metal by welding, but imparts considerable tensile strength and helps to render the junction weak in transverse test. The film is usually discontinuous over any large surface area and its distribution depends on the conditions obtaining during the welding operation. In pressure-welding rods, the careful preparation of a plane surface on the ends and careful aligning, with the application of such pressure as not to produce upsetting or any relative translatory movement, naturally assist in film preservation and in film continuity. The reverse conditions tend to break up or dissipate the film and, hence, yield a much smaller area where we have film-separated contact, and, consequently, increased area of weld.

It was with this hypothesis in mind and with a view to examining its validity that many of the later modified experiments were carried out, and for this reason the experimental conditions were maintained as simple as possible. Thus cup and cone and ball and socket test rods were eliminated. In such experiments the conditions are complex and involve definite but ill-defined relative translatory motion as the ends are pressed together. Further, the shaped ends present a welded area in excess of the cross-sectional area of the rod. This renders a comparison of weld strength invalid.

Since lack of welding is due principally to film interference, the removal or disruption of the film should provide an increase in the area of welded surface. Film disruption may be brought about either by translatory movement or by upsetting. In order to investigate this point, the bars were heated to the desired temperature, and the rod held in the pressure indicator (Fig. 3) was kept stationary, but the one in the pressure applicator was rotated to and fro during the application of the pressure. This afforded the most ready means of disrupting the film and was fairly well under control. One further factor must be mentioned. It was necessary to prepare the ends perfectly square with each other

Fig. 27—Test 213. Longitudinal Section through Bessemer Hydrogen Weld. Unetched. ×100. A few oxide particles along weld show lack of complete reduction.

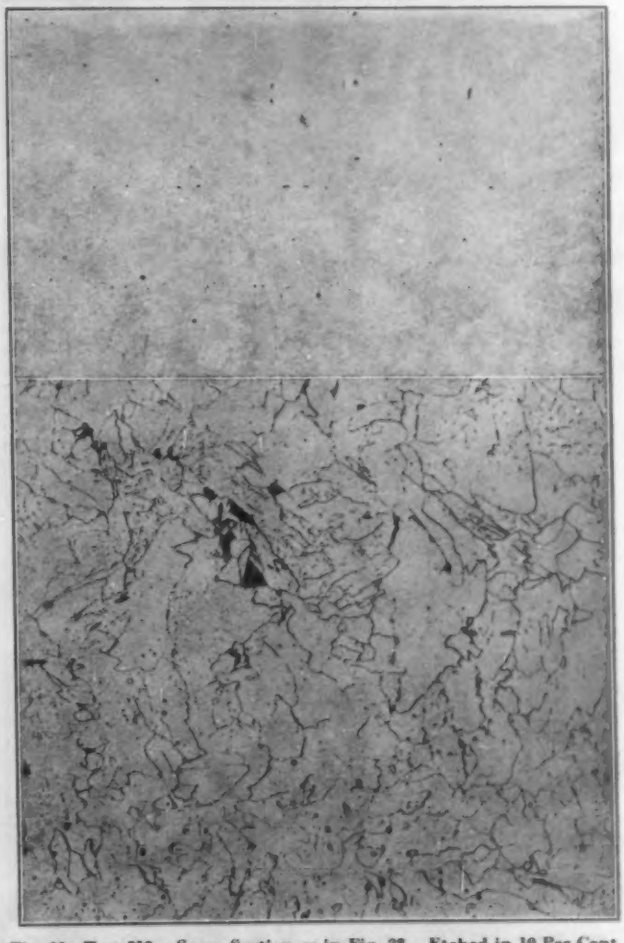


Fig. 28—Test 213. Same Section as in Fig. 28. Etched in 10 Per Cent Alcoholic Nitric Acid. ×100. Tensile test gave good ductility with almost complete fiery fracture.

to prevent one end "rolling off" the other during rotation. The tables indicate where this was done and the specimens are noted as having "true ends."

Many welds were made by this method and pulled in tension. The marked improvement in strength is shown by the data. This is particularly well demonstrated in Table 2 and it is more clearly revealed by the manner in which very good welds are produced at low temperatures, for, on account of the increased strength of the rods, they are less prone to bend or to upset at pressures sufficient to yield intimate surface contact. Thus, with tests 292 to 295 at 1350° C., rotation or translatory movement gives a complete weld with 68,000 lb. ultimate and 20 per cent elongation, while ordinary pressure welds give about 54,000 lb. with no elongation and only about 60 per cent total area welded.

The pressure weld with 60 per cent welded area should show a tensile of about 41,000 lb. The remaining 13,000 lb. tensile strength is imparted by the strength of the oxide film. Such a weld, however, shows no elongation and is brittle.

The tests given in Table 2 were carefully prepared especially to provide definite information on this question and a consideration of all these data is very enlightening. Many of the tests showed notably high strength and good elongations, but in no single case where the specimens were *not* rotated was any elongation observed.

It was to develop this film theory and to demonstrate its effect in interference that the experiments in hydrogen were conducted, although the postulation can almost be regarded as axiomatic. It may, however, be suggested that the factor leading to imperfect welding is lack of intimate surface contact due to insufficient pressure. If that be so, then experiments in a reducing atmosphere under "identical" experimental conditions should give the same results as in air. It should be clearly understood that with very high pressure, resulting in considerable upsetting, good welds could be produced. This, however, is getting a little beyond ordinary pressure welding.

Many hydrogen atmosphere experiments, therefore, were carried out under conditions comparable with those obtaining in the air welds. The results of these are found scattered throughout the tables, and every test made is recorded. The figures shown are sufficient evidence as to the marked improvement obtained. Unfortunately, in many of the earlier experiments no elongation was recorded and this was in large part due to the fact that the test samples were not machined but used in the rough welded state. Tests 272 to 276 (Table 3) and tests 241 to 251 (Table 1), however, provide good examples of results on machined bars. As differing from air welds, it will also be noted that, when almost complete, hydrogen welds give values in excess of the strength of the material.

On account of the unknown effect or strength of films, the true strength of a weld made in air can only be evaluated by reference to the strength of welds where there is, say, 90 to 100 per cent of area welded, and where the function of the film becomes relatively negligible. Such reference shows that welds made in air are weaker than the parent metal (Table 7). Two reasons are advanced for the cause of this:

1. Oxygen embrittlement.
2. Weakness of the junction due to a tendency to contain a preferred grain boundary orientation (Fig. 29).

Similar consideration of 90 to 100 per cent hydrogen welds shows that welding in hydrogen produces a junction stronger than the parent metal. Some such welds give extremely high values; where tested "as welded" the figures are only approximate but can be regarded as demonstrating a definite increase in strength over the parent metal. No attempt is made to discuss the reason for this, as it is beyond the scope of the paper.

Another factor which merits consideration is the effect of intimacy of surface contact. Assuming that two clean metallic surfaces are placed together and heated to a temperature at which it is known that welding can take place, what intimacy of contact is necessary before union occurs? Must contact be of the order of atomic dimensions, which might be called "perfect contact," or is there a considerable sphere of influence through which mutual attraction operates?

As mentioned in the section on Experimental Procedure, two cylinders were drilled through the center and ground to give a level surface. The hole permitted the preparation of a more nearly true plane surface. These were also heated in hydrogen at 1400° C. and the results have been discussed and illustrated in the section on macroscopy. About 90 per cent of the contact surfaces welded. Using the ordinary method of grinding plane surfaces, it is highly improbable that 90 per cent of their areas should be of the order of atomic contact, without the application of pressure. In the opinion of the writers, this experiment demonstrates that such contact is unnecessary. The range of influence over which atomic attraction does take place between the atoms in the

Fig. 29—Test 83. Longitudinal Section through Open-hearth Weld. Unetched. ×100. Shows string of oxide inclusions along line of weld.

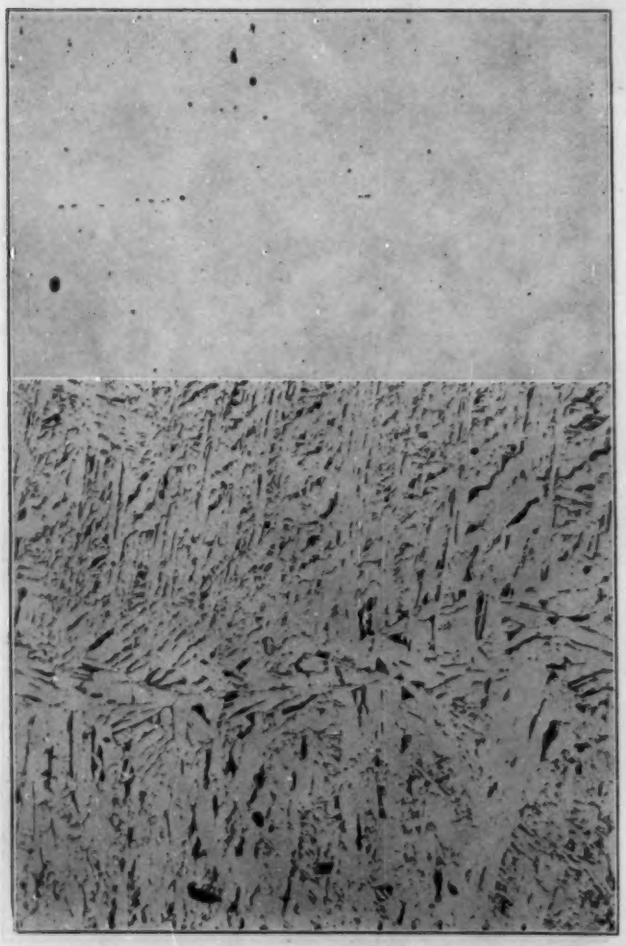


Fig. 30—Test 83. Same Section as in Fig. 29. Etched in 10 Per Cent Alcoholic Nitric Acid. ×100. Shows presence of thin film of oxide, and preferred grain boundary orientation on either side of weld.

two surfaces is an interesting academic point but cannot be pursued further.

In a practical sense, then, it is clear that at the temperatures of our experiments, welding can take place without the application of any pressure and without perfect initial contact being effected between the surfaces to be welded. This, in turn, strongly supports our theory on the effect of oxide films in preventing welding. The lack of welding is not due to the application of insufficient pressure, and hence to lack of surface contact, but to an interference film. This leads us to the important conclusion that simple pressure welding in air cannot produce good welding.

Many reasons have been advanced for a partial breakdown of this interference film; where such lack of continuity exists, true welding takes place. When the oxide film is visible the weld is weak, as films of such thickness have little strength in tension and readily break down under the influence of shearing stresses. When, however, the conditions permit or lead to the formation of a very thin film, the properties are different. Such a film is very strong in tension, as it transmits little or no shearing stress. Thus, the high tensile values which we have obtained can be logically explained. This film can be removed, at least partly, by introducing some translatory motion of one surface relative to the other. This results in a considerable increase in the area of true weld and with a transverse displacement sufficient to completely disrupt the film, complete welding is approximated.

This theory is put forward as an explanation of the appearance of the fracture and of the mechanical characteristics of pressure welds.

Acknowledgments

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Finally, the authors desire to express their appreciation to the executives of the National Tube Co., for permission to publish the results of this investigation.

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Trusses. Problem for Students in Structural Mechanics, F. P. McKibben. Cornell Civ. Engr. (April 1932), vol. 40, no. 7, pp. 107–108 and 120.

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X-Ray Diffraction Patterns. Welding Engineer (April 1932), vol. 17, no. 4, pp. 35–37.

Books

Manual of Electric Arc Welding, by E. H. Hubert. Published by McGraw-Hill Book Co., Inc., 330 West 42nd Street, New York. Table of Contents includes General Information; The Welding Process; Equipment for Welding; Expansion and Contraction; Definitions and Types of Joints; Speed of Welding; Strength of Welds; Design of Joints; Preparation of Work; Making Welds; Welding Special Metals; Practical Welding Applications; Welding Methods; Rules and Regulations; Training Course for Operators; Engineering Data and Tables.

Chemical Plumbing, Leadburning and Oxy-Acetylene Welding, by E. B. Partington. Book for plumbers and heating engineers. Published by The British Oxygen Co., Ltd., Angel Road, Edmonton, N. 18, London. Table of Contents includes: Chapter 1, Plumbing Science. Chapter 2, The Manufacture of Gases. Chapter 3, Lead and Its Alloys. Chapter 4, The Advantages of Leadburning over Soldering. Chapter 5, Different Systems of Leadburning. Chapter 6, Preparation and Making of Seams

and Joints on Sheet and Plate Lead by Leadburning. Chapter 7, Pipe Jointing and Pipe Work in Chemical Plumbing. Chapter 8, The Making of Large Pipes and Bends with Lead. Chapter 9, Chemical Plant Construction, Maintenance and Repairs. Chapter 10, Autogenous Welding (Leadburning) as Applied to Domestic and Sanitary Plumbing. Chapter 11, Leadburning, Accumulation, Maintenance and Repairs. Chapter 12, Oxyacetylene Welding of Iron and Steel, as Applied to Plumbers and Heating Engineers. Chapter 13, Oxyacetylene Welding and Brazing of Non-Ferrous Metals and Alloys. Chapter 14, Miscellaneous.

(*Continued from page 4*)

slower in adopting welding as a useful tool. While no European research can be said to approach either in magnitude or scope the work of the structural steel welding committee in this country, it is clear that structural welding is advancing in acceptance in all parts of Europe as well as in America.

A New Steel Flooring

The development of a new steel flooring after long scientific investigation has been announced by Mellon Institute of Industrial Research, Pittsburgh, Pa. This flooring consists of slabs, 24 in. wide and up to 12 ft. 5 in. in length at present, that are fabricated by preforming two steel sheets and subsequently welding them together in the plane above the neutral axis. A cross-section taken through the width of a completed unit shows four keystone-shaped cells, all connected together near the neutral axis. These four ducts, which constitute each unit, are spaced at six-inch intervals and connect directly, when installed, with the corresponding ducts of the adjacent section of floor slab. This arrangement is described as enabling the utilization of the new floor not only as an efficient load-carrying member, but also as a multiple floor-duct system for handling all types of electrical lines. Such a grouping of parallel cells with six-inch spacing is claimed to permit, at any time, the installation of electrical outlets within a radius of three inches from the exact location required, thus providing permanent electrical flexibility and precluding electrical obsolescence.

It is said that the keystone slab can be installed with ease and rapidity; that it can be bolted, clipped or welded into place across the structural members, affording a working floor for the various trades. This floor is fire-safe; it is adaptable to appropriate finishes and to suspended ceilings and service piping, and has a low weight per square foot.

Rules for Welding

(Reprinted from April 7, 1932, issue of Shipbuilding.)

The paper read at the meeting of the Institution of Naval Architects, and the varied and interesting discussion which it evoked, are sufficient proof of the importance with which the subject of welding in ship construction is regarded by all who are in any way connected with the shipbuilding industry. It is now generally agreed that the process of electric welding can be used either in whole or in part in lieu of riveting for the construction of the strength portion of a ship's hull, although it is also recognized that the utmost caution must be exercised in the development of the new technique if safety is to be assured. Hence, while it is obvious that the classification societies must frame certain rules which shall govern the general principles to be observed both in the actual procedure of welding and in the form of welded joint to be employed, it should be equally obvious that these rules should be sufficiently elastic in their interpretation, and comprehensive in their application, so as not to fetter unduly the freedom of those who are making themselves responsible for the introduction of welding into the art of shipbuilding. A study of the "Provisional Rules for Electric Arc Welding in Ships," which has recently been published by the British Corporation Register of Shipping and Aircraft, reveals the fact that the Corporation has fully recognized the necessity for this point of view in framing their rules.

It may be stated that the rules cover two distinct aspects of the problem, the first dealing with the technique of welding, the materials to be employed, the preparation of test specimens and so on, while the second covers the actual form the welded joint shall take. And since it is recognized that however the welded structure may conform to the rules, the results obtained must of necessity be received with caution, it is laid down that in the classification of the ship, the letters "A. W." shall be employed to indicate that the major portion of the vessel has been arc welded, while the letters "A. W. p." shall signify that a portion only of the main structure has been constructed by this method. With regard to testing the welded joints, it is stipulated that the test specimens should be prepared under conditions which are as nearly as possible the same as those under which the actual constructional work on the ship is carried out. Specimens cut from solid deposits of weld metal must have a tensile strength of not less than 26 tons per sq. in., and an elongation of not less than 16 per cent on a length of eight times the diameter. In order, further, to ensure ample ductility, it is laid down that these specimens of weld metal must be capable of being bent without fracture to an angle of 120 deg. around a bar of twice the diameter of the test piece.

With reference to the actual welded joints, it is recommended that as much as possible of this work should be done under cover implying the maximum of assembly before erection in position on the vessel. The desirability of intermittent welding is emphasized, continuous runs only being employed for water-tight connections and where special strength considerations demand it. All of these rules are provisional in their nature, and they may have to be modified in the light of practical experience.

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-142. Welding engineer desires position as engineer, foreman or instructor. Have had twenty years' experience in oxyacetylene, arc, hand and automatic and atomic hydrogen processes. Experienced in training operators. Have developed welding departments and assisted in development and research work.

A-166. Electric Welder. Considered a first-class operator. Thirteen years' experience both at home and abroad, of which ten years have been spent as a Foreman and Instructor. Passed tests for Class II, A. S. M. E. Code for Unfired Pressure Vessels. Excellent references.

A-167. Arc Welder with ten years' experience. High pressure, marine and boiler work.

A-174. Competent Electric and Oxyacetylene welder desires position. Good technical background. Three years' practical experience and understands production methods thoroughly. Also experienced in training welding operators. Best of New York references. Available on short notice and will go anywhere.

A-175. Expert welder desires position. Am good judge of metals, have executive ability and trustworthy. Experience in all kinds of boiler repair, tanks and pipes. Can also do structural iron work, chipping, caulking and riveting.

POSITIONS VACANT

Electric pipe line welders for work in the Near East. Apply to W3891, Engineering Societies Employment Service, 31 West 39th Street, New York City. Will only consider those who have actually had electric welded pipe line experience in the field.